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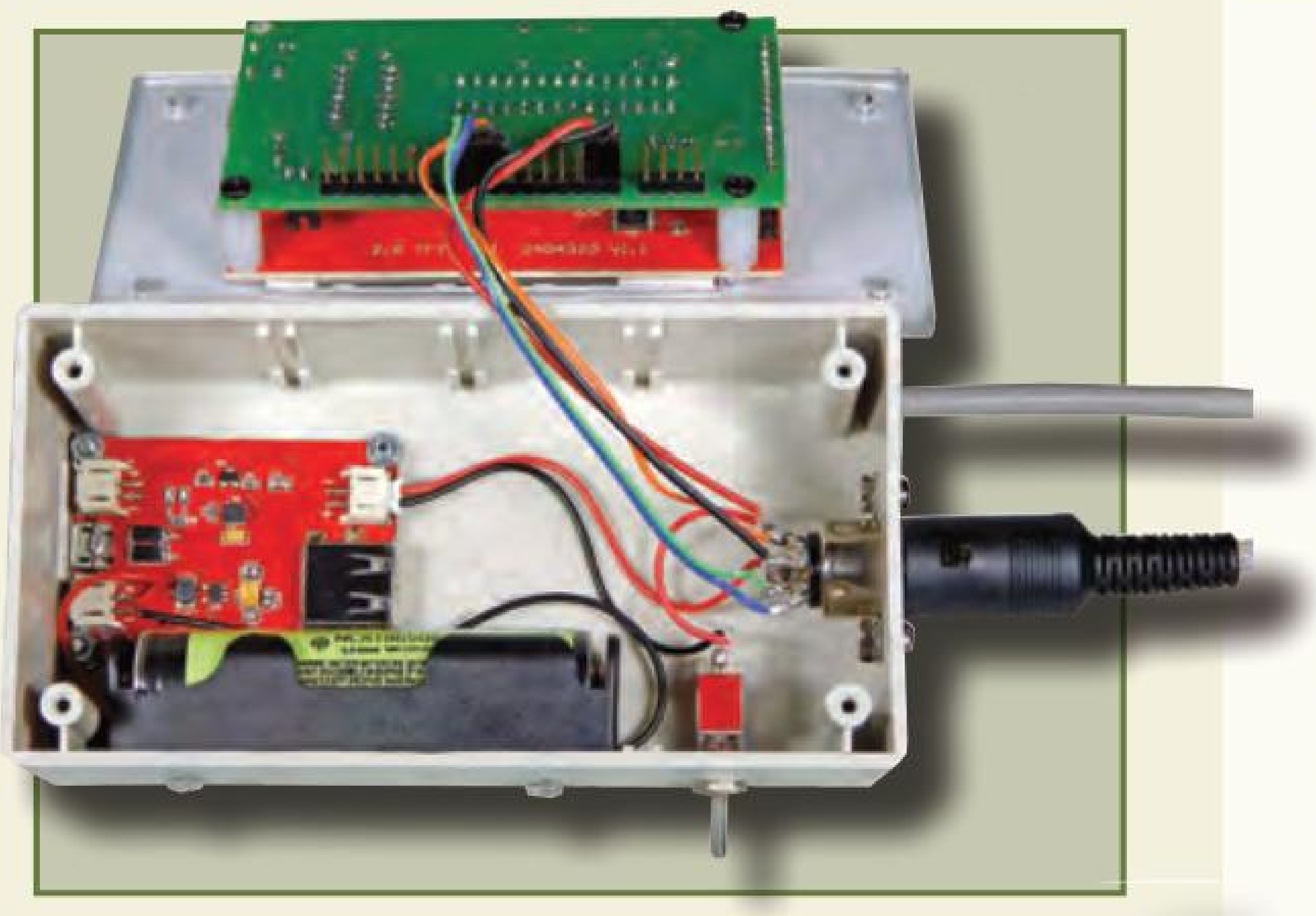

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Our January 2019 issue will be published on Thursday 6 December 2018, see page 72 for details.

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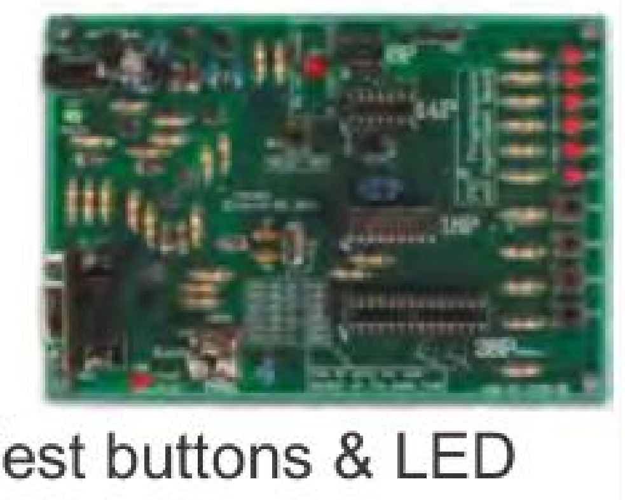

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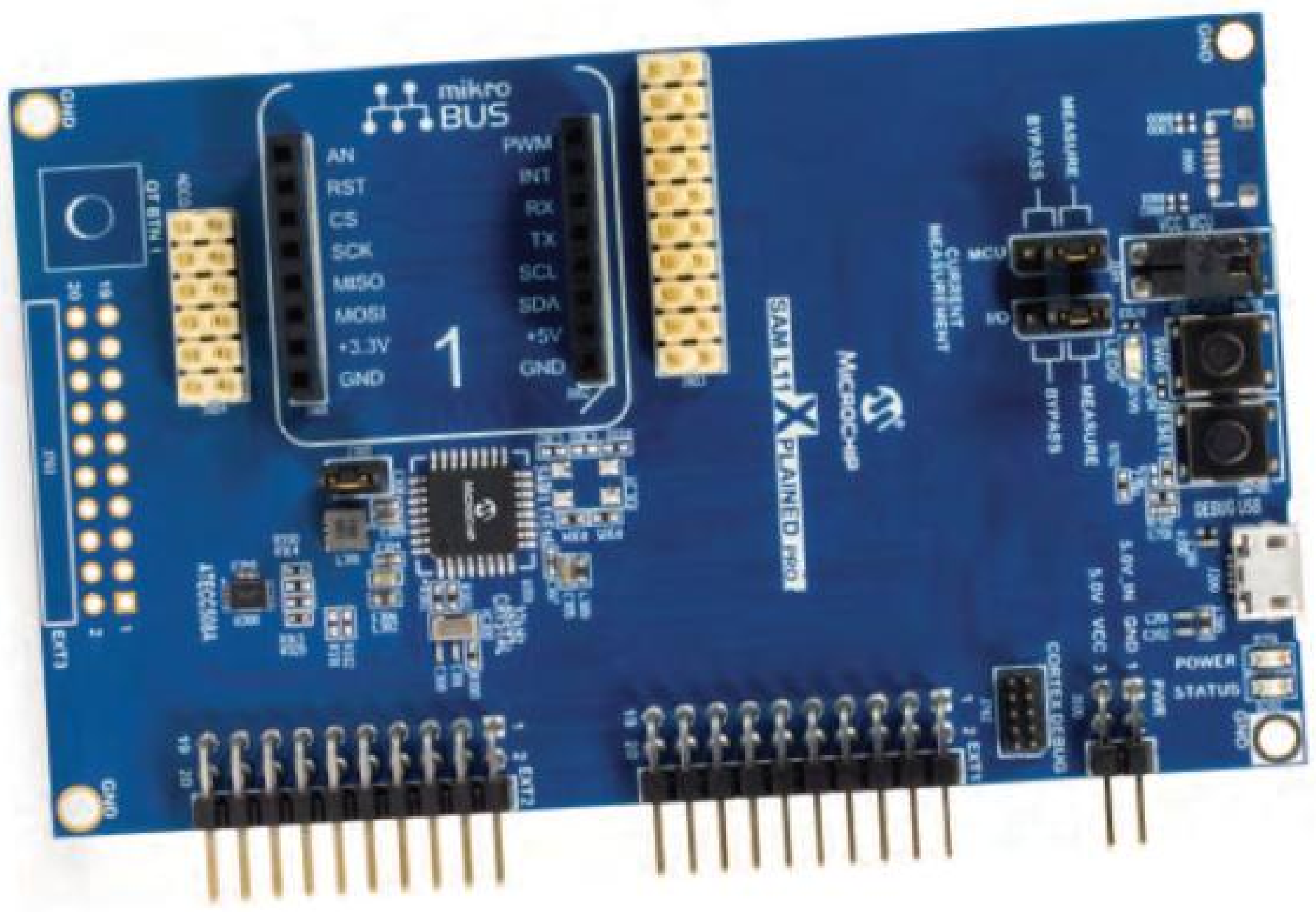
Development Tool of the Month!

SAML11 Xplained Pro Evaluation Kit



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Finally

Matt has kindly invited me to provide December's *Editorial*, as this issue will represent my final involvement in *PE*/*EE*/*EPE* after just over 50 years. It would be very easy to reminisce about that half century, but as I thought about it, I realised I could easily take up four or five magazine pages! (But do see the excellent article by Alan Winstanley – *50 Golden Years Of Practical Electronics* – at: **www.epemag.com/resources.html**)

It has been an interesting, enjoyable and rewarding time, from starting as a sub-editor on *PE* back in September 1968, to buying *EE* and starting Wimborne Publishing Ltd in 1986 (when IPC Magazines made me redundant). Taking over *Hobby Electronics*, *Practical Electronics* and *Electronics Today International* along the way, I edited those magazines from 1978 until Matt took over in 2008. Matt has worked for Wimborne Publishing since 1992, originally as editor of *The Modern Electronics Manual*, so he has clocked up 26 years with us – Thanks Matt.

As I finally retire, we will pass *EPE* to Electron Publishing Limited – a new publishing company owned by Matt – so I know the magazine will be in very safe hands. Stewart will continue to work for *EPE* for a few months to ensure the handover is smooth. As far as you, the reader is concerned, very little will change, except that payments for subscriptions, PCBs and books will go to Electron Publishing at their address in Brighton, instead of coming to Wimborne.

Thanks

Before I go, I would like to thank you, our readers, for all your support over the years (one or two of you for 50 years or more). I have enjoyed our interaction; your comments, praise and positive criticism have kept life interesting.

Thanks must also go to all our contributors – there must have been a few hundred over the years – but our long-standing regulars deserve particular praise for making our life easier with excellent and varied submissions – long may it continue.

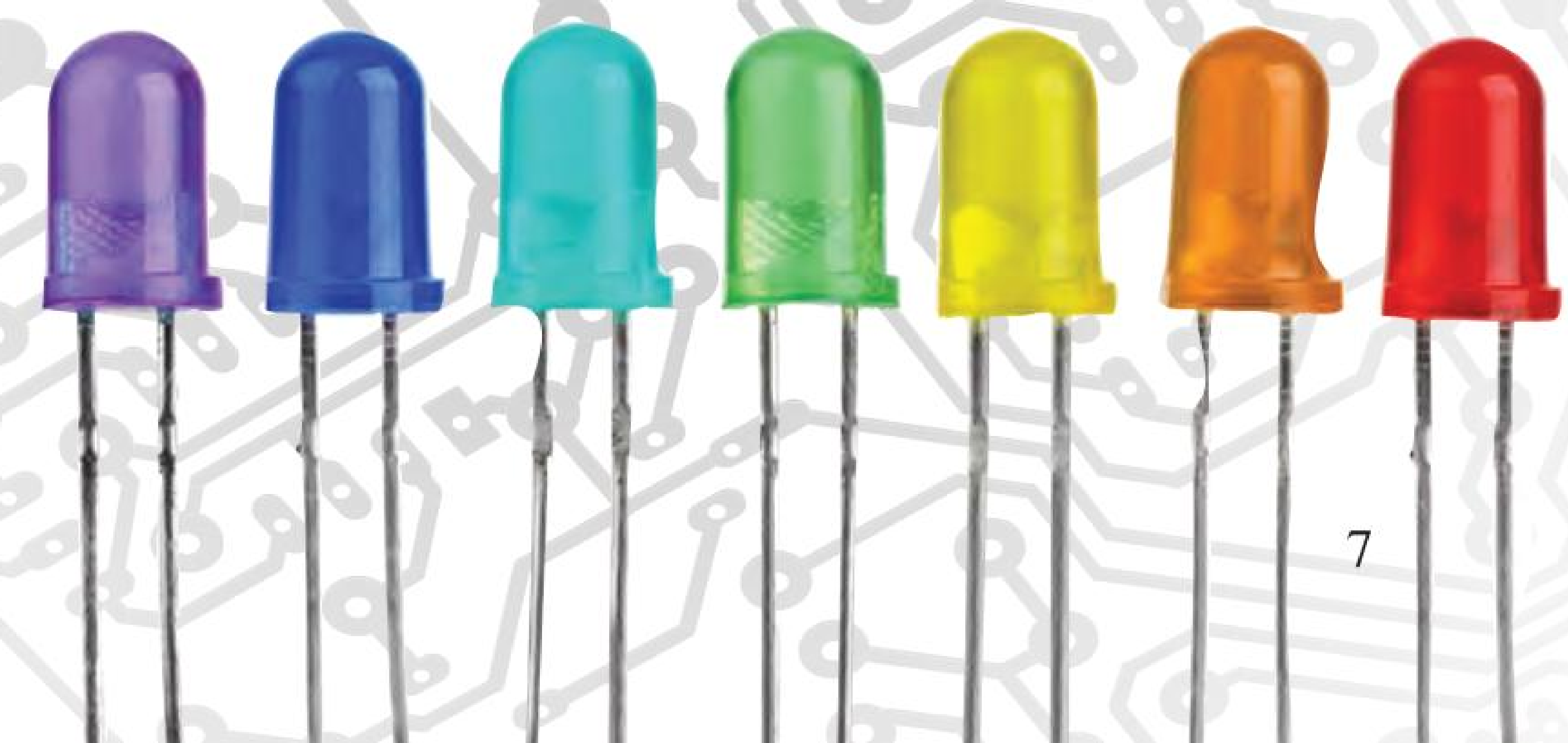
Finally, thanks to all the staff who have worked for Wimborne Publishing, especially my daughter Fay and son-in-law Stewart for helping to keep it all running smoothly in recent years. Not forgetting our friend Marilyn, who has worked for us from the very start of Wimborne Publishing – over 32 years.

I have had an interesting and varied career with great support from Pauline, my wife, who has kept me on the straight and narrow and not complained too much about some of the decisions I've made along the way!

One thing I have always enjoyed is receiving a finished magazine each month from the printer – something tangible I had a hand in producing. Life will change, but I feel now is the right time. Over to you Matt, wishing you the best of luck – I'm sure you will enjoy the ride!

Mike Kenward

Mike Kenward
Publisher



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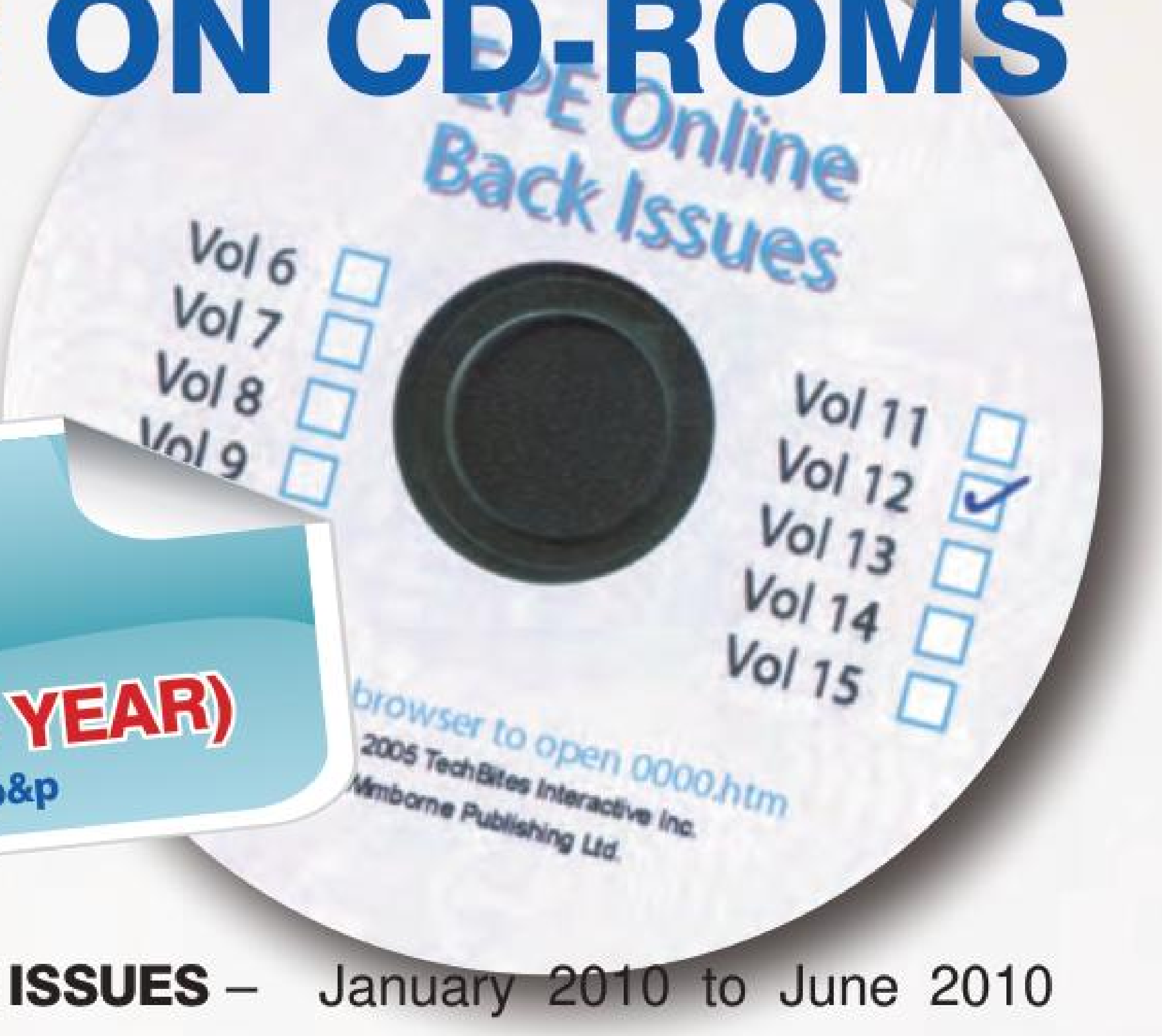

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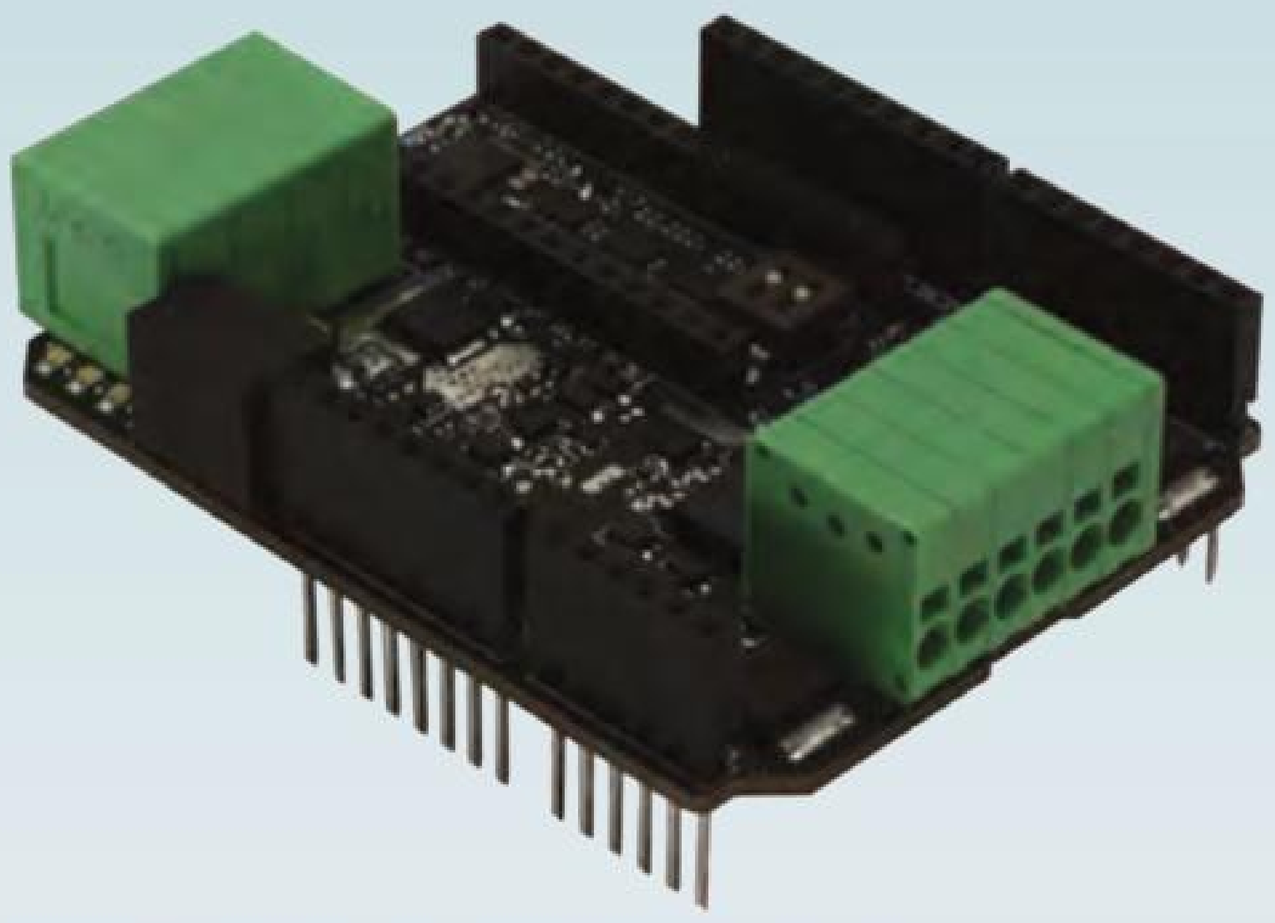
NEWS

A roundup of the latest news from the world of electronics

Power electronics for Arduino

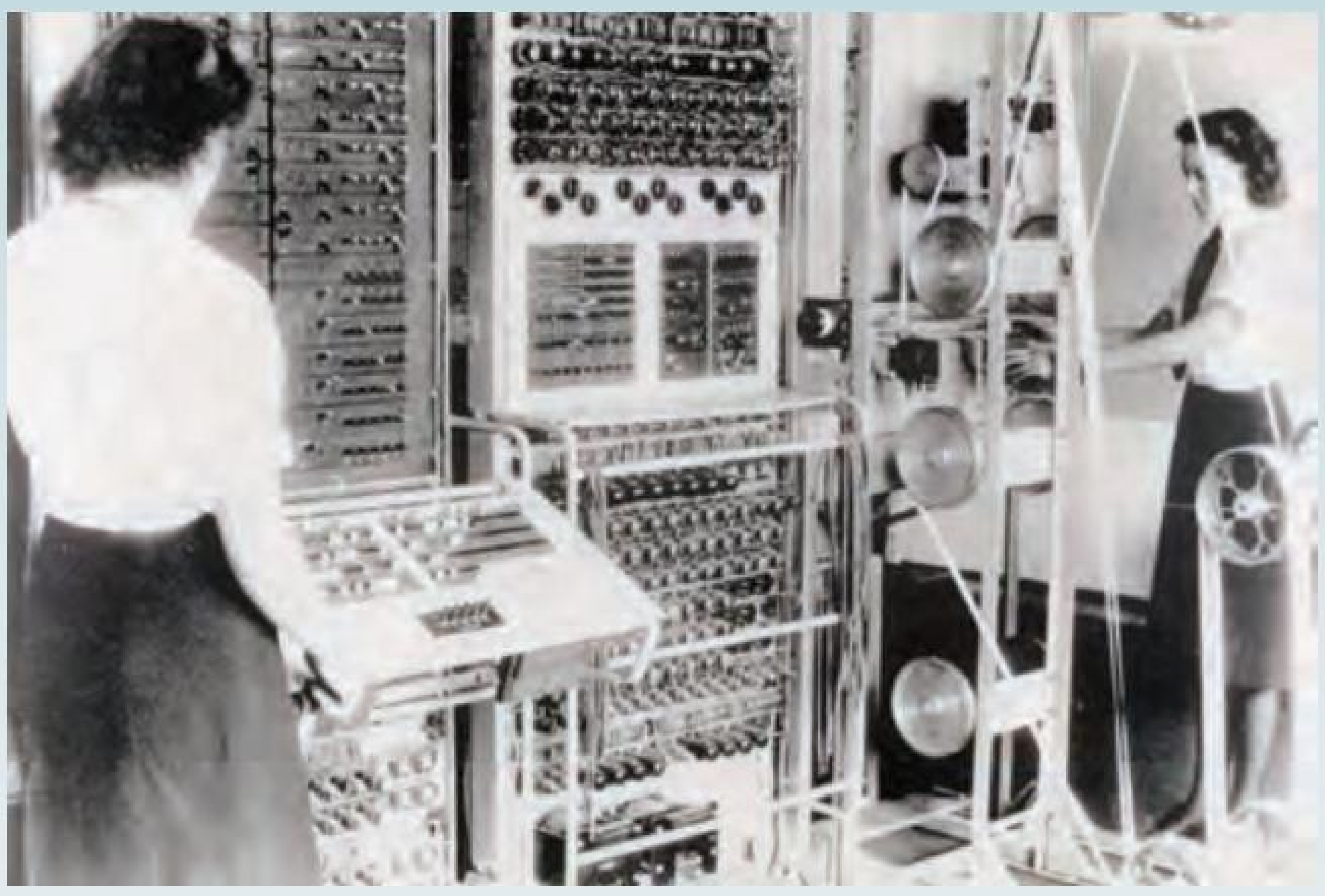

V&VTECH's 6+6 T800 for Arduino

Great news for Arduino fans who are frustrated by the lack of available power electronics options. V&VTECH have launched the 6+6 T800, a new and reliable power shield with 6 or 12 (stacked version) power outputs. It can drive various DC loads; for example, motors, high power LEDs, solenoids, heaters or Peltier modules. Key features of the Shield include:

- Fully pin-compatible with UNO, MEGA and NANO Arduino boards
- Loads can be of any type (inductive, resistive or capacitive)
- Comprehensive output protection
- 4 operation/feedback status LEDs
- Integrated high-efficiency step-down DC/DC converter
- Power connectors with spring-latch technology (anti-vibration protection)
- Simultaneous control of different output voltages
- PWM frequency up to 100kHz.

Further details at: **www.v-vTech.com**

D-DAY: Interception, Intelligence, Invasion


Colossus codebreaking computer at Bletchley Park

Bletchley Park, the museum which preserves and promotes British electronics' 'finest hour' will open an exciting new exhibition featuring an immersive film and display in Spring 2019 to mark the 75th anniversary of the D-Day landings.

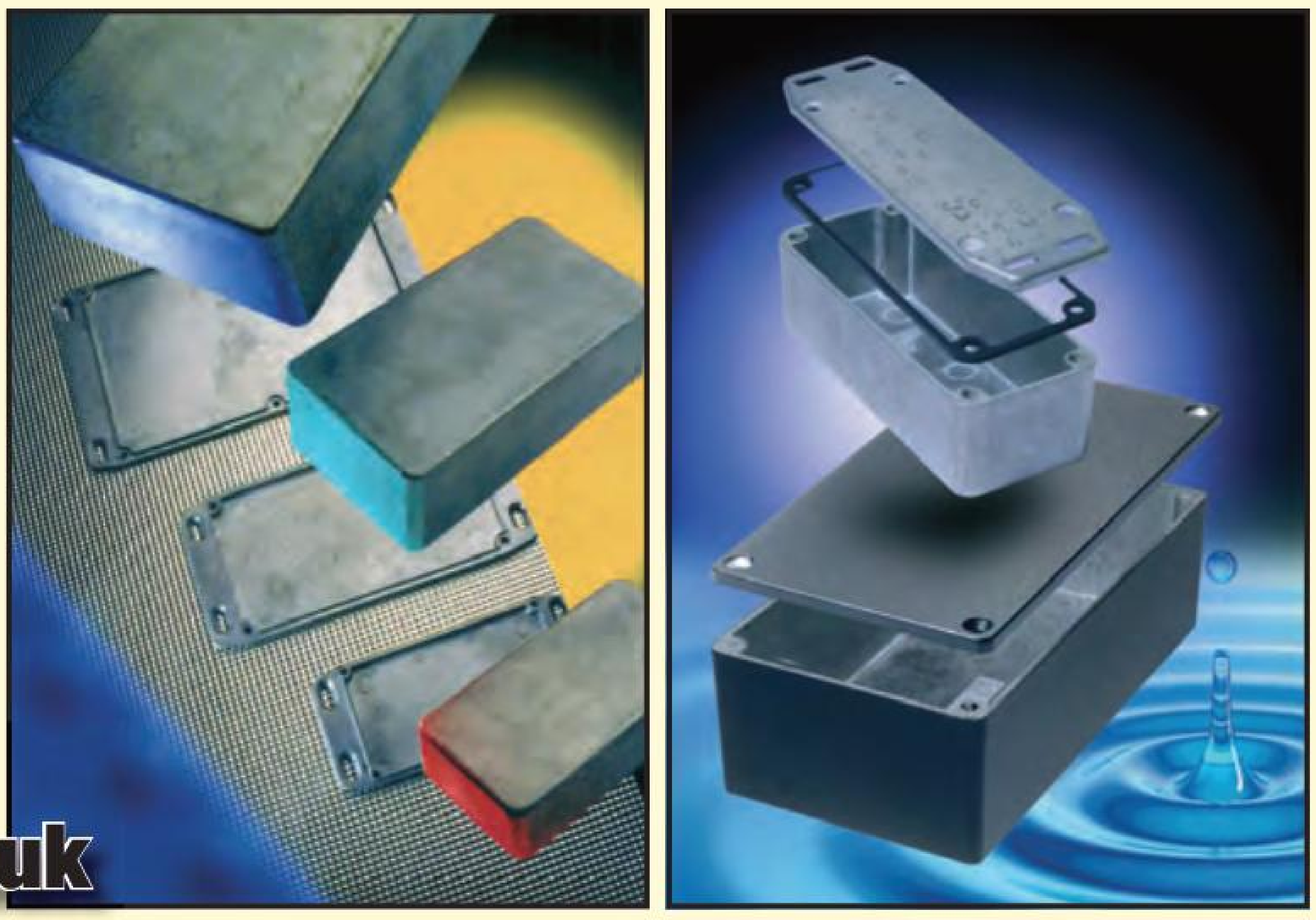
Presenting the vital role Bletchley Park played in informing the D-Day invasion, the exhibition will introduce the people involved and show how different kinds of intelligence were used by the Allies to enable the invasion of Normandy on 6 June 1944.

The vital codebreaking operations at Bletchley Park depended on secure communications and innovative new elctronics technologies. Alongside Bletchley's codebreakers worked the General Post Office (GPO, now BT) engineers, who managed Bletchley Park's secure communications network and delivered cutting-edge information technology such as Colossus, the world's first electronic digital computer. For further details, visit: **https://bletchleypark.org.uk**

UK graphene research accelerates

Wonder material graphene is still to some extent a solution looking for a question, but technology development company Paragraf has opened a graphene R&D facility in Cambridge to help exploit its remarkable properties – single-atom thickness, extremely high conductivity, superb strength, very low weight and high flexibility.

Paragraf is aiming to produce devices that will target product areas including novel transistors, where graphene-based devices could deliver clock speeds several orders of magnitude faster than silicon-based examples; chemical and electrical sensors, where graphene could increase sensitivity by a factor of >1000; and novel energy generation devices tapping into kinetic and chemical green energy sources yet to be exploited by any other technology.



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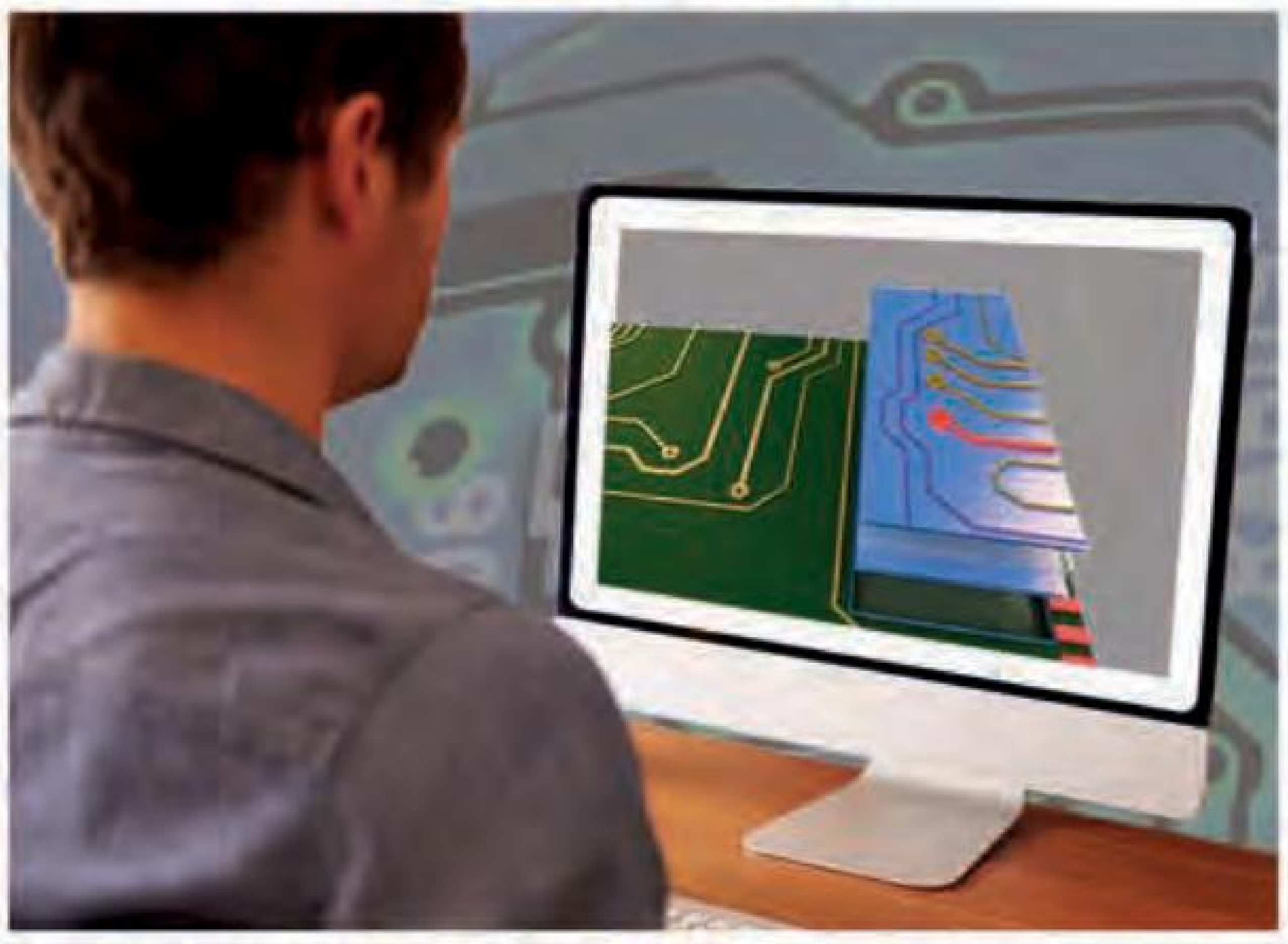
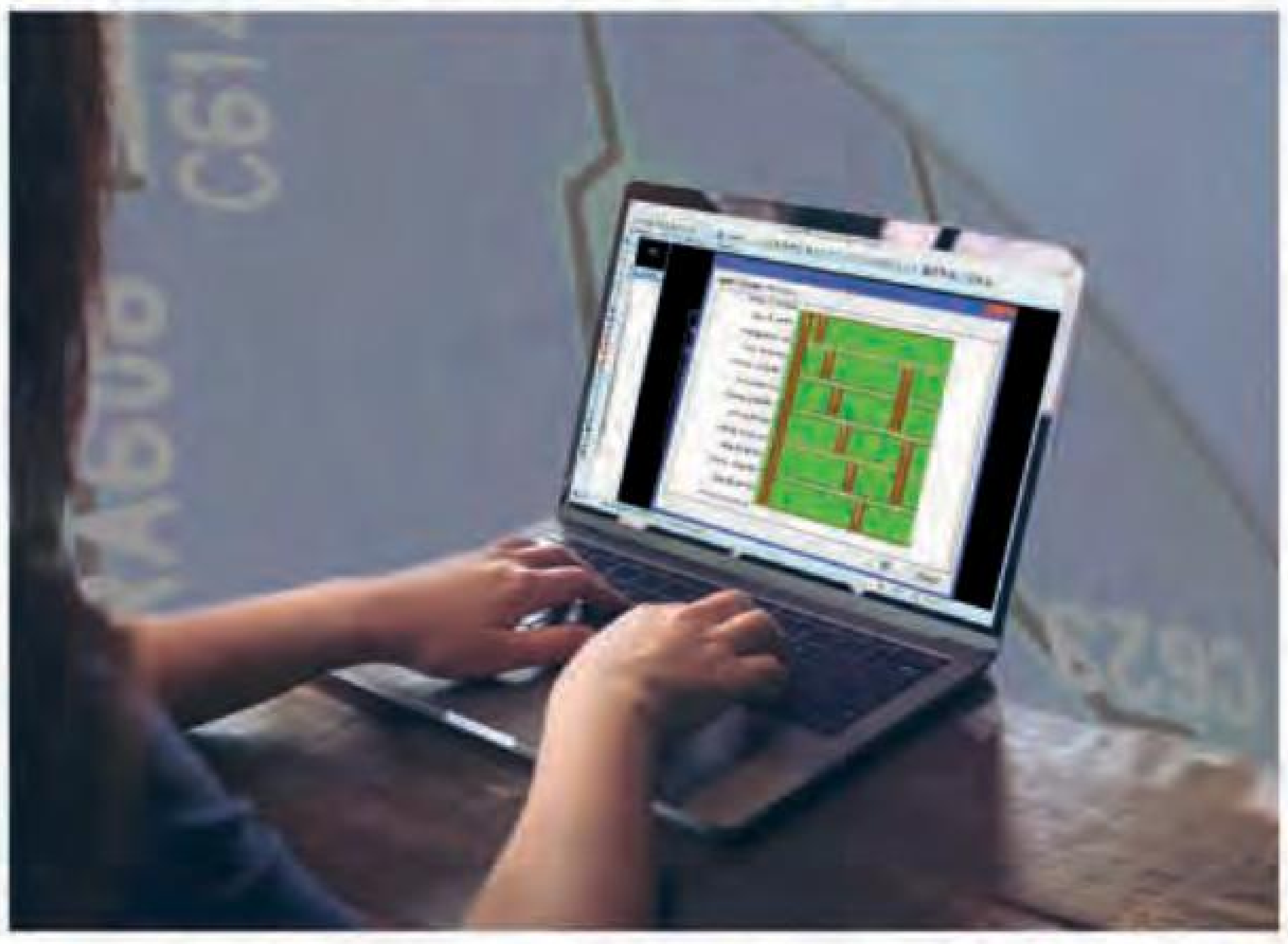


Set design rules that apply in user specified areas of the PCB.

LAYER STACKUP



Control the layer stackup and drill ranges for smarter routing.

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TechnoTalk

Three rants in a row

Mark Nelson

For the third month running, we're in rant mode, examining electronickery that may do more than it simply purports to. This time it's not the IoUT (the Internet of Unwanted Things), but it could be something quite similar. You be the judge!

TIMEO DANAOS ET DONA FERENTES There surely cannot be a single reader who does not remember these immortal words from Virgil's *Aeneid*. Unless, that is you didn't do Latin at school. Regardless of that, those epic words, meaning (more or less) 'Beware of Greeks bearing gifts', are as valid today as when they were written between 29 and 19 BC. In those days, the 'gift' was a wooden horse crammed with insurgents. Nowadays, the ruse has greater subtlety, but anything that looks too good to be true remains something that's unlikely to be in your best interests.

Coming to your local high street: something strange

With hindsight, the wooden horse of classical times was obviously up to no good. Today's Trojan Horse is disguised as a phone box that offers free calls. Yeah right, as if British Telecom would give away free something for which it normally charges a small fortune. So, what on earth is going on?

On the face of it, this sounds marvellous. As you can read at **www.inlink.com**, 'InLinkUK is a new communications service that will replace over 1,000 payphones in major cities across the UK, with new structures called InLinks. Each InLink provides ultrafast, free public Wi-Fi, phone calls, device charging and a tablet for access to city services, maps and directions. InLinkUK is completely free because it's funded through advertising.'

Wow! What's not to like? Well, for a start, BT's commercial partner in this venture is a company backed by Alphabet, the parent organisation of the all-consuming search engine Google, whose 'Don't Be Evil' motto was tersely disputed earlier this year by Margaret Hodge MP, who called the company 'devious, calculating and unethical'.

Criminal concerns

Police forces and local authorities complain that these InLink facilities are magnets for anti-social behaviour and are linked to a wave of drug-related gang violence because they make it simple for addicts to contact their dealers anonymously. In the London Borough of Tower Hamlets the police persuaded the council to stop issuing permits to BT for installing further InLinks. Some local authorities even claim the devices are directly associated with a crime wave of violence among drugs gangs. Other objectors claim the fixtures are intrusive, aesthetically discordant, eyesores or even traffic hazards.

Only a cover story?

Nothing in life is truly free, and as the technology analyst Benjamin Dean told a New York hacking conference back in 2016, 'When you're not paying, you're not the customer – you're the product.' And so it goes. Commentators assert that these 'silver monoliths' are just the sugar coating on an unpleasant pill and hope they all disappear without trace. Blogger Adrian Short (**www.adrianshort.org**) is convinced no good will come of InLink kiosks. 'InLink is about much more than helping Londoners get online and helping brands flog them stuff,' he argues. 'It's about building a citywide urban sensor network to monitor and respond to environmental conditions and human activity at a far finer grain than current systems. Will our privacy be protected? Will our lives be improved? Who will really be in control? We don't really know, because the InLink network as a whole is getting no more scrutiny than, well, a bunch of phone boxes.'

Big Brother is watching you

Is he? Well, he might be. How do InLink users – or passers-by – know what information these kiosks are capturing? I for one don't know, and InLink's detailed media pack doesn't let on. Adrian Short reckons that cameras in the kiosks could be streaming real-time high-definition video back to a central data centre for capturing face recognition, gait analysis and sophisticated threat detection analysis. He asks: 'Is the microphone for monitoring ambient noise levels, recording people's conversations or detecting gunfire?' Local authorities considering planning applications deliberate only on whether a specific location is suitable for accommodating a slender item of street furniture. They are not required – or even authorised – to consider the potentials of a citywide or even nationwide information-gathering mechanism. Is anyone doing this?

Stealth software revealed

Should citizens have the final word on whether and when their personal information is used? In New York, where the service goes by the name of LinkNYC, activists have glued stickers over the system's camera portholes. Interviewed by Sky News, Matt Bird, general manager of InLinkUK, told the broadcaster: "We have no interest whatsoever of tracking individuals, whether it's on Wi-Fi or other means. We care about utilising data for good. The built-in cameras are turned off, while we try to think about the best use for them for community good." In other words, the cameras could be activated quite soon.

But as a crusading website has revealed (**https://theintercept.com**), an undergraduate researcher has found software code – accidentally made public on the Github website – that indicates developers may be actively planning to track users' locations. Opposition to this comes from several quarters: the national American Civil Liberties Union and the Electronic Frontier Foundation, and more locally from anti-surveillance action groups such as ReThink LinkNYC and the Stop LinkNYC coalition. All of them seek to arouse greater public awareness of these kiosks' potential to collect personal information and facilitate mass surveillance.

Where next now?

The holding company behind these kiosks has global ambitions. Last year it secured $150m of equity funding to bring its highly-successful and fast-growing Link product and other smart city technologies to cities and transit systems around the world, also to develop the next generation of its technology platform. Its network currently includes LinkNYC, InLinkUK, and LinkPHL in Philadelphia. There are also kiosks in New York's subways and on the Southeastern Pennsylvania Transit Authority's network of trains. Here in Britain, more than 200 InLink kiosks are already up and running in Swansea, London, Leeds, Glasgow, Southampton, Gateshead, Newcastle and Sheffield. Will your community be next?

NET WORK

by Alan Winstanley

Yellow peril

ANYONE WITH A UK LANDLINE will know how much slimmer the traditional *Yellow Pages* printed directories have become over the years. Once doubling as a good doorstop, the *Yellow Pages* brimmed with local information and obligatory adverts for every type of local trader under the sun. As the Internet started to roll out, buyers turned to Google instead (eventually leaving the Yahoo Directory and Alta Vista trailing in the dust) and the black art of website search-engine optimisation (SEO) evolved. Online buyers became better informed and they were soon spoilt for choice.

Many old search brands, including the Open Directory (DMOZ) and LookSmart are remembered at **www.searchenginehistory.com**, which cites the post-war work of Dr Vannevar Bush who called for scientific research into ways of making 'information' readily accessible. His work, published in *The Atlantic* journal in July 1945, offered a glimpse of his futuristic-sounding ideas to employ photocells, cathode ray tubes, thermionic tubes (valves), punch cards, chemical papers, relays and more contemporary technology in order to sort and display information and automate the data retrieval process. Search Engine History also attributes the origins of search engine indexing principles themselves to Gerard Salton's 56-page book, *A Theory of Indexing*, published in 1975. His highly intensive analysis applied signal-to-noise ratio, differentiation, frequency distribution, discrimination values and advanced algebra to the problem of indexing useful 'information' – major complexities that Google and others would face 25 years later when indexing (and monetising) information gleaned from the web.

Echo Input (disc) adds Alexa awareness to a loudspeaker via Bluetooth or 3.5mm audio

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The last ever Yellow Pages printed directories are dropping through Britain's letterboxes right now

After more than half a century of churning out phone books in a lemon-coloured livery, *Yellow Pages* is finally halting production. A shrunken and sorry-looking 'final edition' has just landed on the author's doormat. Apart from Google, UK local traders can be found on Yell at **www.yell.com** or via the Yell app. Rival *Thomson Directories* has also switched to online only, and can be searched at **www.thomsonlocal.com**

Word of mouth is often the best salesman/woman, and many local traders and businesses don't even have websites these days, relying instead on Facebook and social media chatter to drum up business.

Amazon Echoes success

Amazon is releasing a slew of updates and accessories for its Alexa-powered Echo smartspeakers ready for the Christmas rush. The puck-sized Echo Dot now has a fabric covering similar to Google's Home Mini pod, together with audio quality improvements. The larger Echo Plus speaker also has enhanced speakers and its built-in hub is designed with IoT home control in mind. The device now hosts a built-in temperature sensor for climate control systems. A new bass-boosting wireless Echo subwoofer is also mooted this year.

Coming soon is Amazon's new speaker-free interface gadget called Echo Input, a 12mm-high disc with four microphones, Bluetooth and 3.5mm audio that gives an existing loudspeaker Alexa awareness. Not every PR-puffed-up device actually makes it to market though: the Echo Connect telephone adapter floated a year ago would have provided a telephone landline interface but never made it to the UK, possibly because Skype and VoIP compatibility made more sense given the likely running costs.

Amazon's wedge-shaped Echo Show table-top device with built-in colour LCD has also received a worthwhile facelift. The new 2018 version released in the US sports a 10-inch high-definition display and fabric finish, a 5MP camera, Amazon's Silk

MONDAY, AUGUST 6
Snoqualmie, WA
72°
Try "Alexa, show me the weather at 5PM"

An updated Echo Show has a 10-inch LCD display

Echo Auto is Amazon's car dashboard accessory, currently being trialled in the US

and Firefox web browsers, integrated streaming movies and TV shows, a built in Zigbee hub, upgraded stereo sound and compatibility with the Ring video doorbell system that Amazon bought earlier this year. Skype calling is also promised as a matter of course, making domestic telephony as seamless, hands free and carefree as possible.

For motorists, a new in-car Amazon Echo Auto is now being floated in the US. Currently available by invitation only, the $49 dashboard accessory hooks to a smartphone and promises to bring Alexa, Audible talking books and all the usual Amazon services to drivers. Its UK availability is not yet known. The updated product line-up launches in the UK on 11 October, though interested buyers might want to look for end-of-line sales of discontinued versions, or wait for new offers in the forthcoming Black Friday sales around 23 November.

Vishing victims

This month's *Net Work* has a timely reminder about current trends in both online and telephone fraud. Some saddening and disturbing reports have surfaced, describing how some people have succumbed to an alarming upsurge in vishing scams, sometimes causing innocent and unsuspecting victims to lose substantial cash or savings. Vishing – voice phishing – is a variant of classic phishing con tricks that we have all experienced, when social engineering is used to manipulate and trick people into revealing logins or personal data, perhaps by logging into bogus websites or clicking on dubious adverts that install malware or steal private credentials. Armed with this data, criminals then proceed to empty a victim's bank account without mercy. These often-risible phishing scams usually contain poor grammar, nonsensical English or misspellings, or they might address you using just your email address. As I typed this paragraph, a phishing scam arrived in my inbox imploring me to 'click here' to renew my vehicle tax online to 'avoid unpleasant consequences'. I traced the link to a hacked web server in Malaysia, where a bogus Wordpress page was hosting some suspect Javascript. Fraud lurks everywhere you look online.

So-called 'spearphishing' is a highly targeted and very authentic-looking attack aimed at individuals: perhaps they will receive a phony email from their dentist or golf club addressed to them personally, inviting them to 'click here' for more details. Some scams are highly sophisticated, however. *Net Work* readers no doubt know how bogus overseas call-centres, notably in Bangladesh and Pakistan, try to fool their victims into granting remote access to their computers, on the pretext of fixing a (non-existent) fault for a hefty fee. Typically they try to install Teamviewer on your PC and then take full control. Back in the November 2015 column I wrote how an overseas BT call centre agent was possibly suspected of leaking customer details to criminals who would then call up victims claiming to be from 'Microsoft Windows' or 'BT Broadband' and charging a fee to repair a supposed fault. Many other calls are just dialled randomly, hoping for a reply. Interactive voice response (IVR) systems are also used: one unsolicited call received by the author kicked off with a female robo-operator asking about 'my accident' and waiting for me to say 'yes' so that I could be booted upstairs to a human call handler.

Vishing takes telephone scams to a new level by phoning the targeted victims and impersonating an institute like their bank or building society. One lady reportedly lost £160,000 ($200,000) to these very convincing scammers who fooled her completely into thinking her accounts had been compromised and she needed to urgently move all her savings into bogus 'safe' accounts instead, which the crooks proceeded to drain. Eighteen months on, she remains £90,000 ($117,000) out of pocket, reports the *Daily Mail*. A major problem for victims of APP or Authorised Push Payment fraud is that because customers are directly instigating the transfer of funds themselves, financial institutes are unlikely to reimburse them for their losses, as they were not negligent. More than £100m was lost to APP fraud in the first six months of 2017 alone, says the UK's Payment Systems Regulator, but tighter controls and system checks are needed and ways of compensating victims are now under consideration. APP fraud should not be confused with AFF or Advance Fee Fraud, where funds are paid in advance for something that never materialises, including rental and lonely-heart scams.

BEC fraud gets down to business

It isn't just individuals who fall victim to scammers: a fraud known as BEC or Business Email Compromise sees phony emails supposedly sent by a company executive to staff workers who are instructed to arrange money transfers into (bogus) bank accounts. The fraud can be helped by lax email authentication systems, sloppy administration or blind obedience: in some cases, what is called 'malicious compliance' might see disaffected staff who feel they are 'not paid to think' just blindly follow orders without question. BEC fraud is hitting all manner of businesses in the UK, and the FBI's Operation WireWire aims to disrupt it globally (see **https://bit.ly/EPE-Dec18-FBI**). Recent operations were summarised by the US Department of Justice at: **https://bit.ly/EPE-Dec18-DoJ**

Some social engineering villains go to great lengths to shape their victim's behaviour. British TV presenter Matthew Wright was conned out of £10,000 ($13,000) when a construction project went awry: he thought he was emailing his (genuine) builder but a fraudster had set up a bogus email address containing one character different from the genuine one, and the crook gradually profiled the 'real' builder until he could brazenly impersonate him. Wright happily communicated with the crook and transferred hard cash before the penny dropped. Swapping out characters in URLs or addresses to fool people this way is easily done, with '1' and 'L', or '0' and 'O' often looking identical at first glance.

Staying safe online, being vigilant and questioning as necessary, following your instincts and safeguarding against fraud have become essential life skills in today's online world. In Britain, victims can report fraud to Action Fraud (**https://bit.ly/EPE-Dec18-fraud**) and plenty of advice is available on Action Fraud's website. Consumers can also visit Get Safe Online at: **www.getsafeonline.org** for everyday sensible advice.

Maplin: the next chapter?

The electronics hobbyist retailer Maplin Electronics, which crashed under a mountain of debt earlier this year is about to make a comeback. At the time of writing, the web page **https://www.maplin.co.uk** exclaims, 'We're back!' and invites visitors to sign up to receive a 10% discount. The website's full-screen 'hero graphic' alludes to a line-up of consumer gadgets: VR headsets, flat screens, Amazon Echo, IP cameras and smartphones. Maplin's intellectual property (branding, website, customer data and trade marks) has been bought by none other than Peter Jones, the Dragon's Den (Britain's 'Shark Tank') entrepreneur, says *The Register*. He also rescued the Jessops photography retail brand. Expect to see a redesigned Maplin website launched possibly by the time you read this.

See you next month for more *Net Work*. You can contact the author at: **alan@epemag.net**

Touchscreen Altimeter / Weather Station
SOLAR PANEL CHARGE IN
USB CHARGE IN
ALTITUDE:
11
metres above GND
TOUCH TO CHANGE MODE OR UNITS
POWER

Touchscreen Altimeter

by Jim Rowe

This accurate altimeter has a bright colour touchscreen to display altitude in feet or metres, atmospheric pressure, temperature and relative humidity. It can show all readings at once or provide a larger display for altitude – the most important one if you're flying!

This design is useful for hang gliders, where the touchscreen facility is especially useful.

Some ultralights also have a dearth of cockpit instruments – just take this one along with you when you fly! Plus, you can use a solar panel to keep the battery charged on long flights.

The display is based on our popular *Micromite Touchscreen*, and the sensing setion of the *Altimeter* uses two electronic modules which have been recently reviewed in *EPE:* the Elecrow GY-68 digital barometer module (in this issue) and the AM2302/DHT22 temperature and humidity module (*Cheap Electronic Modules*, *Part 4*, *EPE*, April 2018).

Of course, even if you have no intention of leaving the Earth's surface, this project will also provide a useful weather station display with the advantage of touchscreen control.

And if you ever decide to climb Mt Everest, this little unit can even cater for that: Everest's summit is reckoned at 8848m above sea level (we go up to 9000m!) and our temperature sensing goes down to –40°C (Everest seldom goes this low during the climbing season).

Battery charge may be slightly problematical – so best take a solar charger panel with you!

By the way, we are well aware that you can purchase various weather stations with colour displays very cheaply. But they don't have the touchscreen facility nor the ability to simply highlight one reading, such as temperature.

Presentation

The *Touchscreen Altimeter* is housed in two small plastic cases, one for the *Touchscreen Micromite BackPack* and the other for the two sensor modules. The larger UB3 case is 130 × 68 × 43mm (L×W×H) and houses the touchscreen, together with the single 18650 lithium-ion cell which powers the project and the Elecrow charger/upconverter module (see *Cheap Electronic Modules*, *Part 8*, *EPE*, August 2018).

The smaller UB5 case measures 83 × 54 × 31mm (L×W×H) and houses the two sensor modules. The cases are connected via multi-way cable – you choose its length to suit your purpose.

So why have two cases instead of one? We tried using a single larger case, but it had problems with internal heat build-up which compromised the reading accuracy. More on this anon.

Circuit details

Fig.1 shows how all the modules are connected together.

Starting with the DHT22/AM2302 temperature and RH module, we won't go into its operation in depth since we've covered it before (*EPE*, April 2018).

The main things to know are that it has its own dedicated 8-bit microcontroller to measure relative humidity via a special polymer capacitor and temperature via a negative-temperature coefficient (NTC) thermistor.

Each time the micro uses these to take a set of measurements, it calculates the corresponding temperature and relative humidity (RH) and sends them out as a serial 40-bit data package via the DATA line.

The data is encoded using a special pulse-width-modulation system and this is decoded by the Micromite and displayed on the touchscreen.

Every DHT22/AM2302 module is calibrated during manufacture with its calibration coefficients saved in its micro's one-time programmable memory. These coefficients are used to achieve impressive levels of measurement resolution and accuracy.

The RH measurement range is from 0-100%, with rated resolution of 0.1% and an accuracy of ±2%, while the temperature measurement range is from –40 to +80°C with a resolution of 0.1°C and an accuracy of ±0.5°C.

Specifications

Altitude range	0-9000m (0-29520ft) above MSL or GND, with 1m resolution and ±1m accuracy
Temperature range	–40°C to +80°C, with 0.1°C resolution and ±0.5°C accuracy
Relative humidity measuring range	0 to 100%, with 1% resolution and ±2% accuracy
Barometric air pressure range	300-1100hPa (mBar), with 0.1hPa resolution and ±0.12hPa accuracy *(from 950 to 1050hPa, at 25°C)*
Power requirements	230mA at 5V, (380mA at 3.7V from inbuilt 18650 Li-Ion cell)

The Elecrow GY-68 barometer-altimeter-temperature sensor module is based on the BMP180 device made by Bosch Sensortec, a division of the large German firm Robert Bosch (**www.boschsensortec.com**).

The BMP180 is based on piezo-resistive MEMS technology – MEMS stands for 'MicroElectroMechanical Systems'.

It uses a tiny sensor element which flexes mechanically in response to changes in atmospheric pressure, with the flexing sensed by measuring changes in the element's resistance.

The BMP180 chip is fitted inside a tiny 3.6 × 3.8 × 0.93mm metal package, which has a very small vent hole (about 0.5mm diameter) in the top to allow the sensor element access to the outside air.

Apart from the sensor element, there are three other functional blocks inside the device: an ADC (analogue-to-digital converter) to make the measurements, a control unit which also provides the I^2C serial interface for communicating with an external micro, and finally an EEPROM, which has 22 bytes of storage for the device's 11 × 16-bit calibration parameters.

As with the DHT22/AM2302, every BMP180 device is individually calibrated during manufacture and the calibration parameters are saved in its EEPROM.

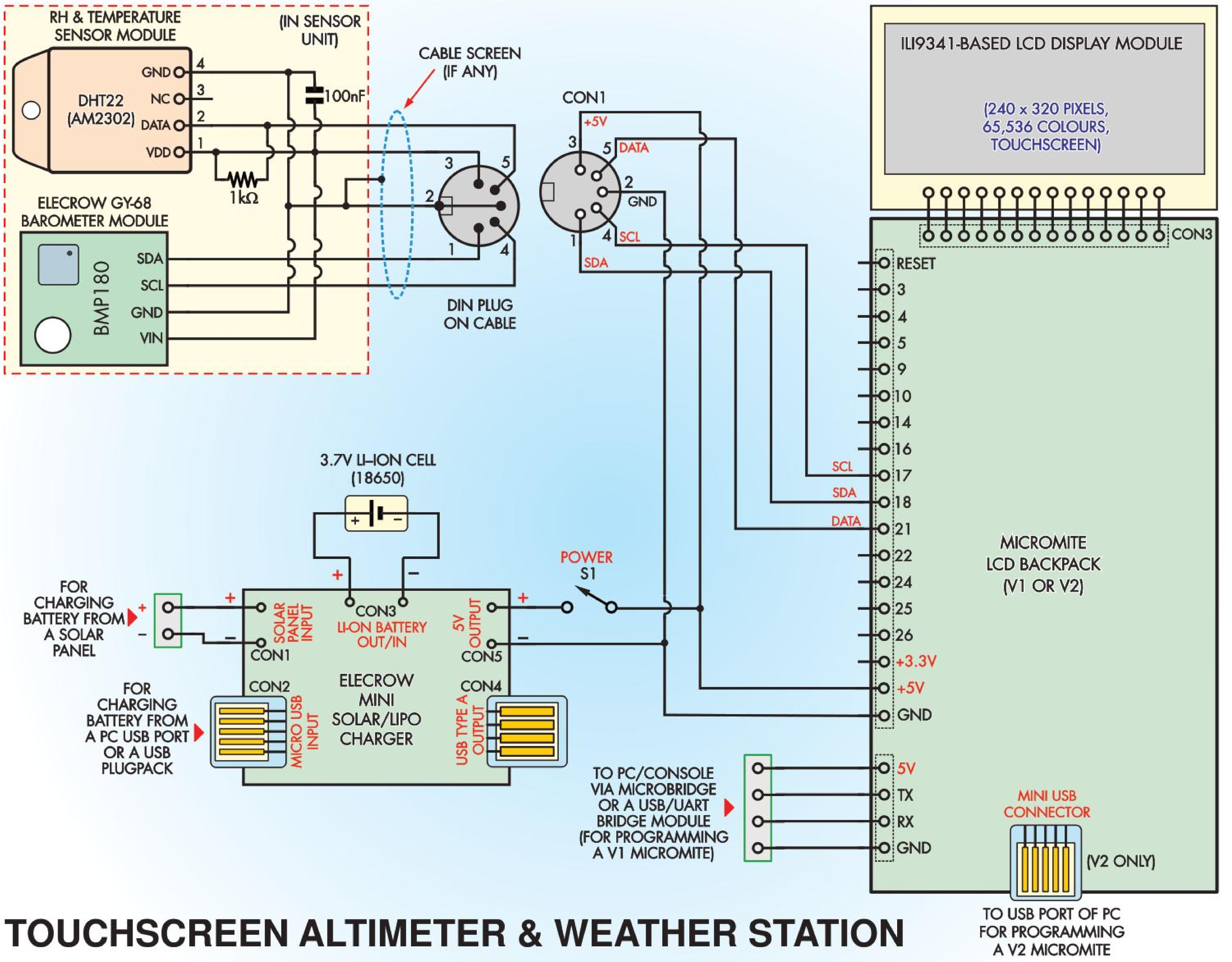
So the external micro can read these parameters and use them to correct that sensor's readings for offset, temperature dependence and other factors.

With suitable software, the BMP180 can provide accurate measurements of barometric pressure, temperature and altitude above mean sea level (MSL).

The quoted relative accuracy for atmospheric pressure is ±0.12hPa (hectopascals) from 950-1050hPa at 25°C, while the absolute accuracy is quoted as –4/+2hPa over the range from 300-1100hPa and for temperatures from 0-65°C.

All this from a chip which only draws about 12µA from the +5V supply!

Both sensing modules have the ability to measure air temperature. We're taking advantage of this in our *Touchscreen Altimeter* project, as the software for the Micromite takes the average of the two temperatures to achieve optimum display accuracy.


RH & TEMPERATURE SENSOR MODULE
(IN SENSOR UNIT)
DHT22 (AM2302)
GND
NC
DATA
VDD
4
3
2
1
100nF
1kΩ
ELECROW GY-68 BAROMETER MODULE
BMP180
SDA
SCL
GND
VIN
CABLE SCREEN (IF ANY)
DIN PLUG ON CABLE
CON1
+5V
DATA
GND
SCL
SDA
ILI9341-BASED LCD DISPLAY MODULE
(240 x 320 PIXELS, 65,536 COLOURS, TOUCHSCREEN)
CON3
RESET
3
4
5
9
10
14
16
17
18
21
22
24
25
26
+3.3V
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MICROMITE LCD BACKPACK (V1 OR V2)
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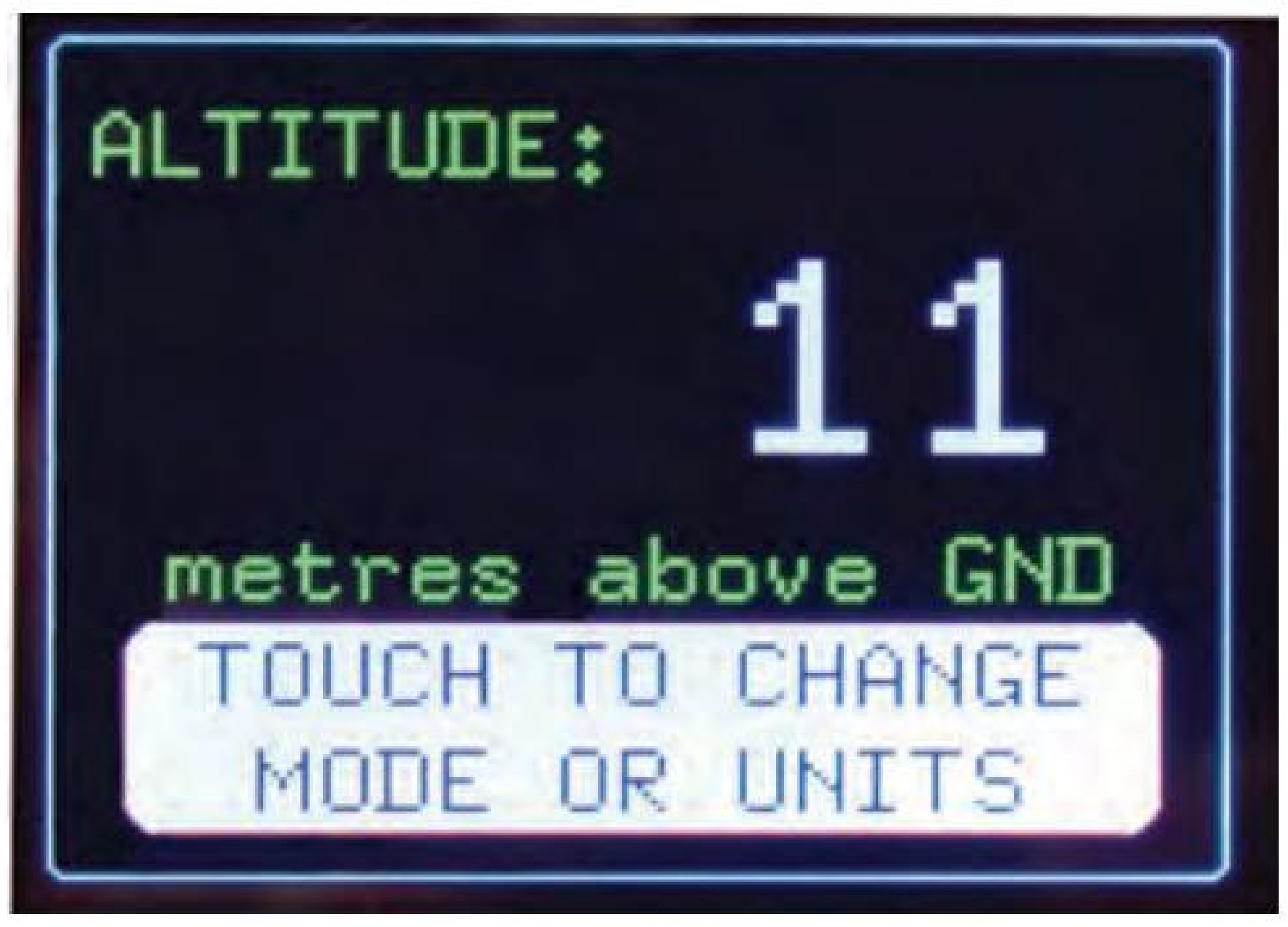
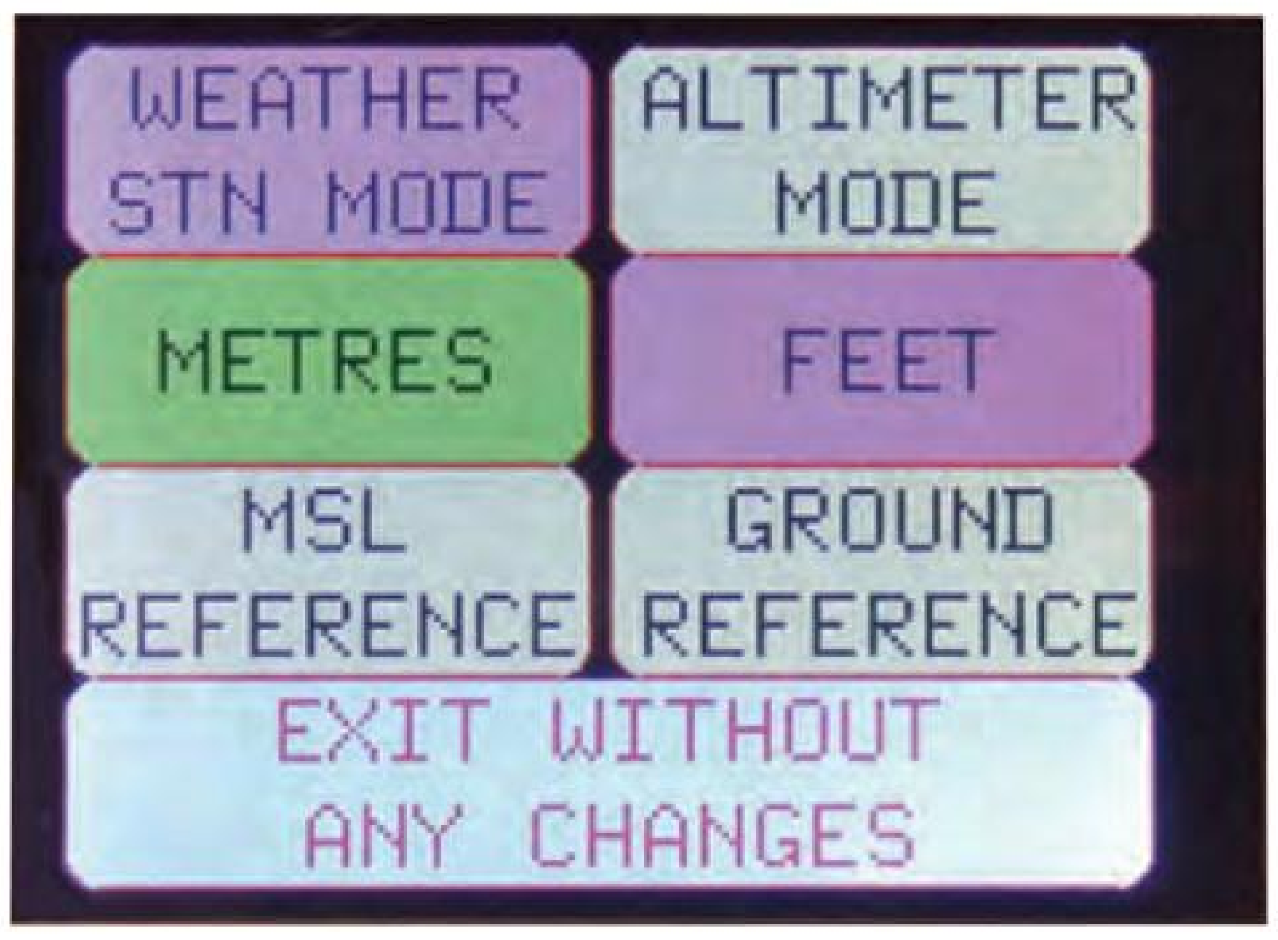
SOLAR PANEL INPUT
CON1
CON3
LI-ION BATTERY OUT/IN
5V OUTPUT
CON5
CON2
MICRO USB INPUT
ELECROW MINI SOLAR/LIPO CHARGER
CON4
USB TYPE A OUTPUT
TO PC/CONSOLE VIA MICROBRIDGE OR A USB/UART BRIDGE MODULE (FOR PROGRAMMING A V1 MICROMITE)

TOUCHSCREEN ALTIMETER & WEATHER STATION

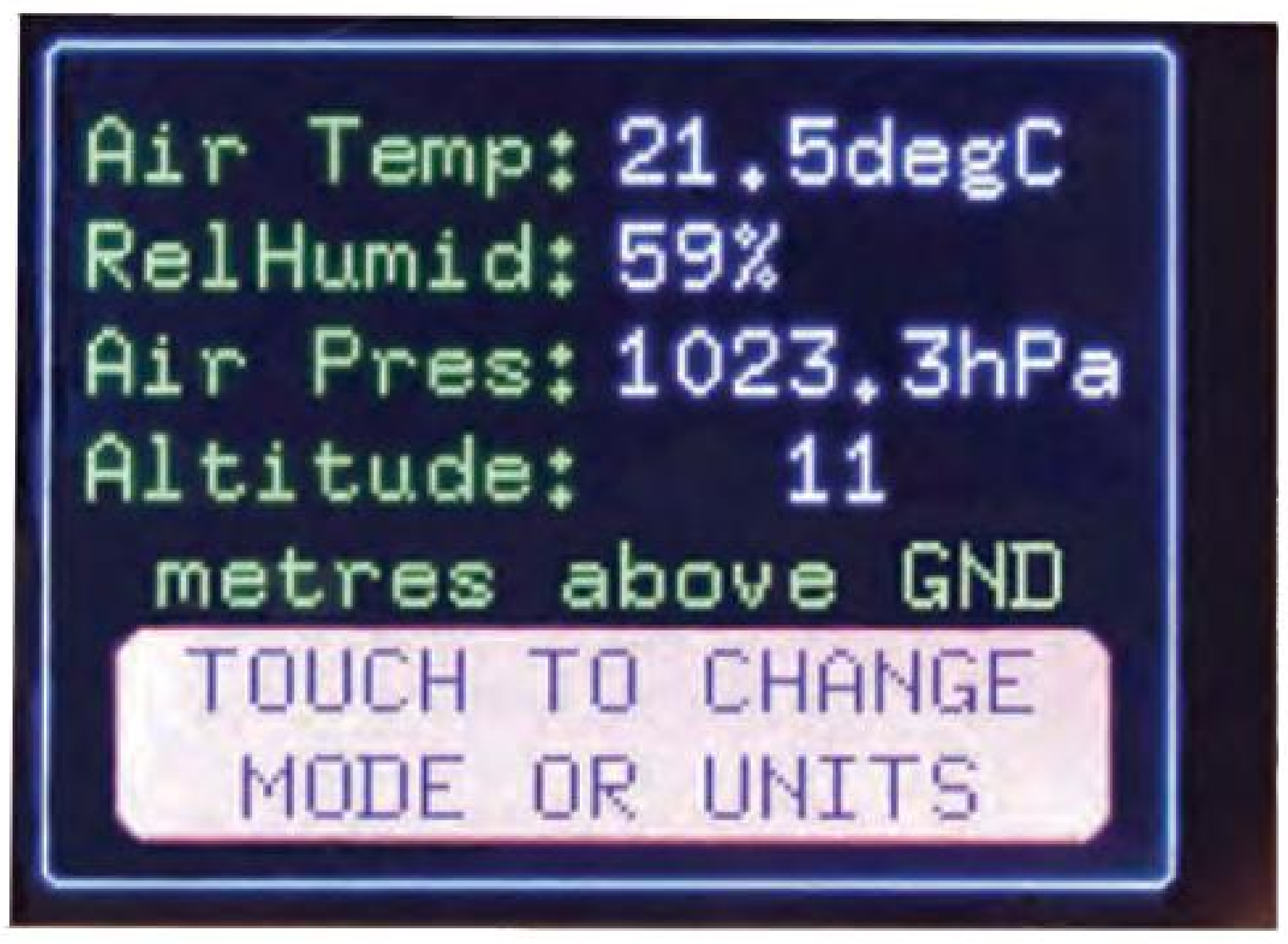
Fig.1: the *Altimeter* is based on two low-cost modules, one measuring barometric pressure and the other temperature and relative humidity. Their readings are monitored by a *Touchscreen Micromite BackPack,* which displays the data on a touchscreen readout. An 18650 cell supplies power, kept charged by a mini solar/USB charger.


ALTITUDE:
11
metres above GND
TOUCH TO CHANGE
MODE OR UNITS

Here's the display in *Altimeter* mode. The green text shows the altitude units (metres or feet) and the reference level (MSL or GND).


WEATHER STN MODE
ALTIMETER MODE
METRES
FEET
MSL REFERENCE
GROUND REFERENCE
EXIT WITHOUT ANY CHANGES

When you touch the button at the bottom of either of the other displays, this 'Change Settings' display appears, allowing you to make changes.


Air Temp: 21.5degC
RelHumid: 59%
Air Pres: 1023.3hPa
Altitude: 11
metres above GND
TOUCH TO CHANGE
MODE OR UNITS

Here's the display in *Weather Station* mode. Again, you can touch the button at the bottom to change any of the settings or switch to *Altimeter* mode.

Lithium battery and charging

Since its main application is as an altimeter for ultra-light aircraft and hang gliders, we needed a battery power supply which was compact and light in weight, with reasonable battery life.

Barometric pressure and altitude

Atmospheric pressure is due to the weight of air immediately above your location.

The primary SI unit for pressure is the pascal (Pa), which is equivalent to a force of 1 newton (N) per square metre.

A column of air one square centimetre in cross section, measured from sea level to the top of the Earth's atmosphere, has a mass of about 1.03kg and a weight of 10.1325N.

This corresponds to a pressure of 101,325Pa or 1013.25hPa (hectopascals), since 1hPa = 100Pa. So the 'standard atmosphere' is defined as 1013.25hPa.

The actual barometric pressure at any particular location depends upon its elevation, or altitude, with respect to mean sea level (MSL), because the higher the elevation, the lower the weight of air directly above you and the lower the pressure.

It also depends on various aspects of the weather, including the amount of moisture in the atmosphere – ie, the relative humidity (RH).

The relationship between air pressure and altitude is usually defined as the Barometric Formula. This can be written as:

$$\text{Altitude} = 44330 \times \left[1 - \left(\frac{P}{P_o}\right)^{\frac{1}{5.225}}\right]$$

where altitude is in metres, P is the measured air pressure and P_O is the air pressure at MSL, or 1013.25hPa. If you substitute 1013.25 for P in the above formula, the result will be 0 metres which is MSL.

With those factors in mind, we settled on a single 18650 lithium-ion cell as the battery, together with one of the Elecrow *Mini Li-Ion Charger/Converter* modules.

A quality 18650 cell like a Panasonic, Sanyo or similar will have an energy storage capacity of between 1500 and 3400mAh (milliamp-hours) when fully charged.

So since the project draws about 230mA at 5V (mainly to power the Micromite and its backlit LCD), which translates into about 390mA drawn from the 3.7V Li-Ion cell (allowing for converter efficiency), it should be capable of running the unit for between three and eight hours.

Watch those 18650s!

As we pointed out in a recent article, there are 18650s . . . and 18650s. Don't be tempted to use a 'bargain' or unknown brand (did someone mention eBay?), especially one labelled higher than 3400mAh – they're a con, as no such 18650 cell exists yet!

Similarly, any 18650 cell you use should have protection circuitry built in – it makes the cell slightly longer but it means it won't overcharge or overdischarge.

However, we've seen cheap 'protected' cells which contain no more than a spacer to make them look like they're protected. Our tip is to always buy a reputable brand.

Charging

The Elecrow charger module allows charging of the 18650 Li-Ion cell from the USB port of a PC or a low-cost USB plugpack or alternatively, from a small solar (photovoltaic) panel.

It also provides a DC-DC converter to boost the 3.7V terminal voltage of the Li-Ion cell to the 5V level needed to run the *Micromite BackPack* and the two sensor modules. This second function only comes into operation when power switch S1 is closed.

One minor shortcoming of Elecrow's *Mini Charger* module is that it doesn't provide any 'pass through' of the USB data lines between its USB input and output connectors (CON2 and CON4). But this only affects the initial uploading of the *Weather Station/Altimeter* software into the Micromite – not normal operation.

Luckily, the initial software uploading to the Micromite can be easily done, as shown in the circuit.

You will need to connect the 5V/TX/RX/GND pins of the Micromite to one of the USB ports of your PC via either a Microbridge module or a standard low-cost CP2102-based USB/UART bridge module.

If you're using one of the newer V2 Micromites (strongly recommended), it's even easier since these have a Microbridge built in. So all you need to do for uploading the software is connect the Micromite's mini-USB connector directly to a USB port of your PC or laptop.

Why two cases?

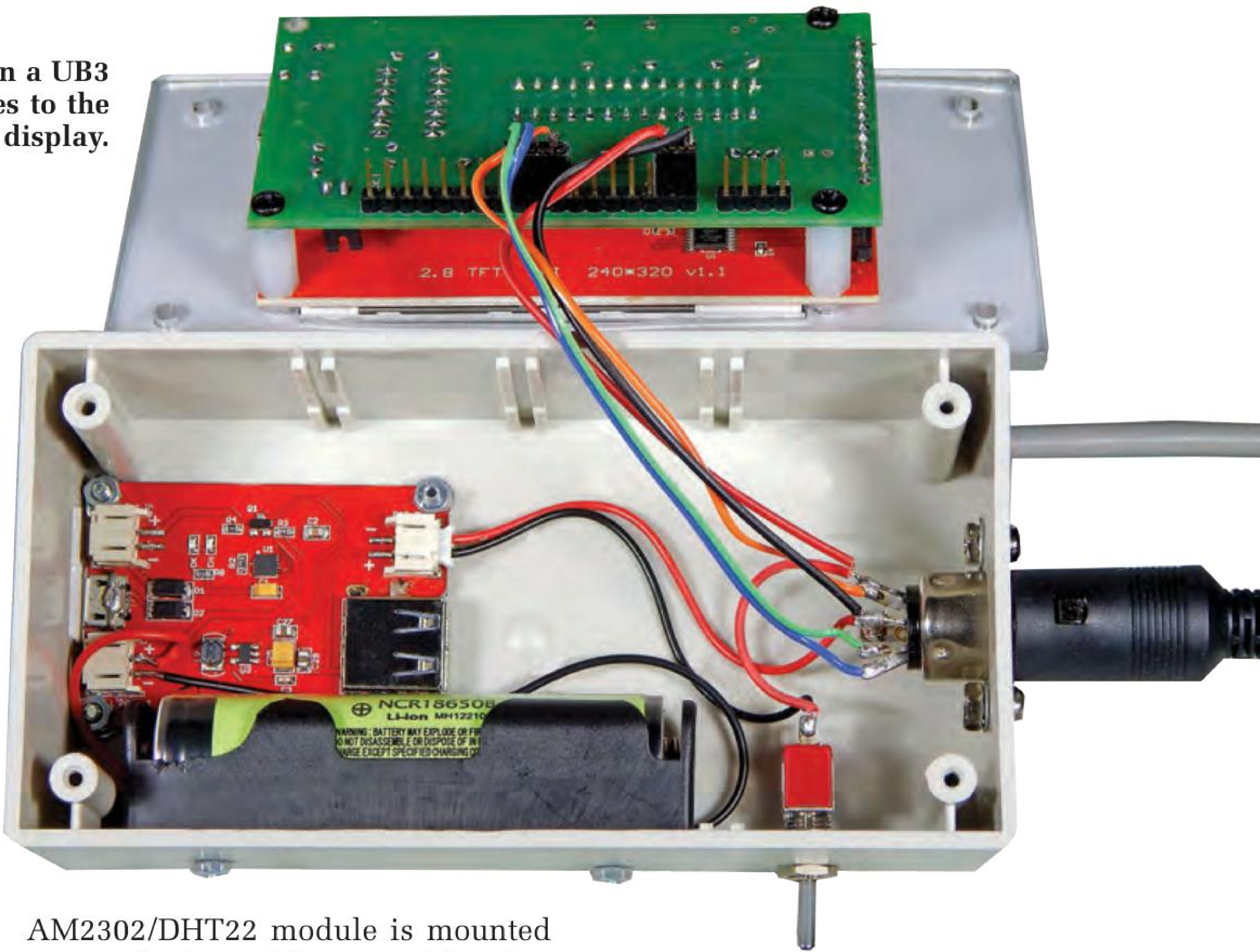
Now let's turn to the physical side of the project and explain why the project is split into two small cases, instead of a single case.

We started with everything squeezed into a single UB3 case, the smallest practicable size to fit everything in.

We soon discovered that the heat from the Micromite and (mainly) its LCD Touchscreen backlighting steadily raised the temperature inside the case, so that the apparent air temperature rose significantly, giving spurious readings. So that's why we ended up with two separate cases.

As shown in the photos, the two sensor modules are mounted in the bottom of the smaller case, which has two 3mm-diameter ventilation holes in the bottom of the case to ensure that conditions inside are substantially the same as those outside.

Inside the main unit, the *Micromite BackPack* and its *Touchscreen* are mounted under the case lid, while the Elecrow *Mini Charger* module is mounted on the bottom at the left-hand end.



Interior view of the main unit, housed in a UB3 Jiffy box. The *Micromite Backpack* fixes to the box lid with a cutout for its touchscreen display.

The Li-Ion cell holder is mounted on the front side of the case, as low as possible so that it just clears the underside of the Micromite PCB when the lid assembly is attached.

In order to do this, the *Mini Charger* module is attached using only three screws, and in addition, part of the cell holder's 'side flap' is cut away at the positive end.

Also mounted on the front side of the case to the right of the Li-Ion cell holder is power switch S1, a mini SPDT toggle switch.

Construction

As shown in the layout/wiring diagram of Figs. 2 and 3, assembling both units is pretty straightforward because we are just linking up prebuilt modules.

But before you can begin the assembly, you'll need to prepare both boxes by drilling and cutting the various holes. To do this, follow the diagram of Fig.4 and 5 closely.

You can avoid cutting out and drilling the holes in the UB3 box lid/front panel if you buy one of the laser-cut front panels from the SILICON CHIP online shop.

Another point to note is that before fitting any of the components into the larger UB3 case, you'll need to cut away four of the moulded splines inside the front side of the box, as shown in Fig.4. This is to allow the 18650 Li-Ion cell holder to be attached to the inside, down low enough to clear both the *Mini Charger* module and the underside of the *Micromite LCD BackPack* module. The splines can be cut away with a sharp hobby knife, or a small rotary tool if you prefer. Once the two boxes have been prepared you can fit the two modules into the UB5 box. Here the AM2302/DHT22 module is mounted inside the box at lower right, using three M2.5 × 8mm machine screws and nuts, with three extra M3 hex nuts used as spacers.

The GY-68 barometer module is mounted in the same way at upper left, in this case using a single M2.5 × 8mm machine screw and nut, with a single M3 nut again used as a spacer.

The cord grip gland can also be fitted in the 12.5mm hole at the left-hand end – but don't tighten up the outer cord gripping nut at this stage (only when you have fed the cable through it).

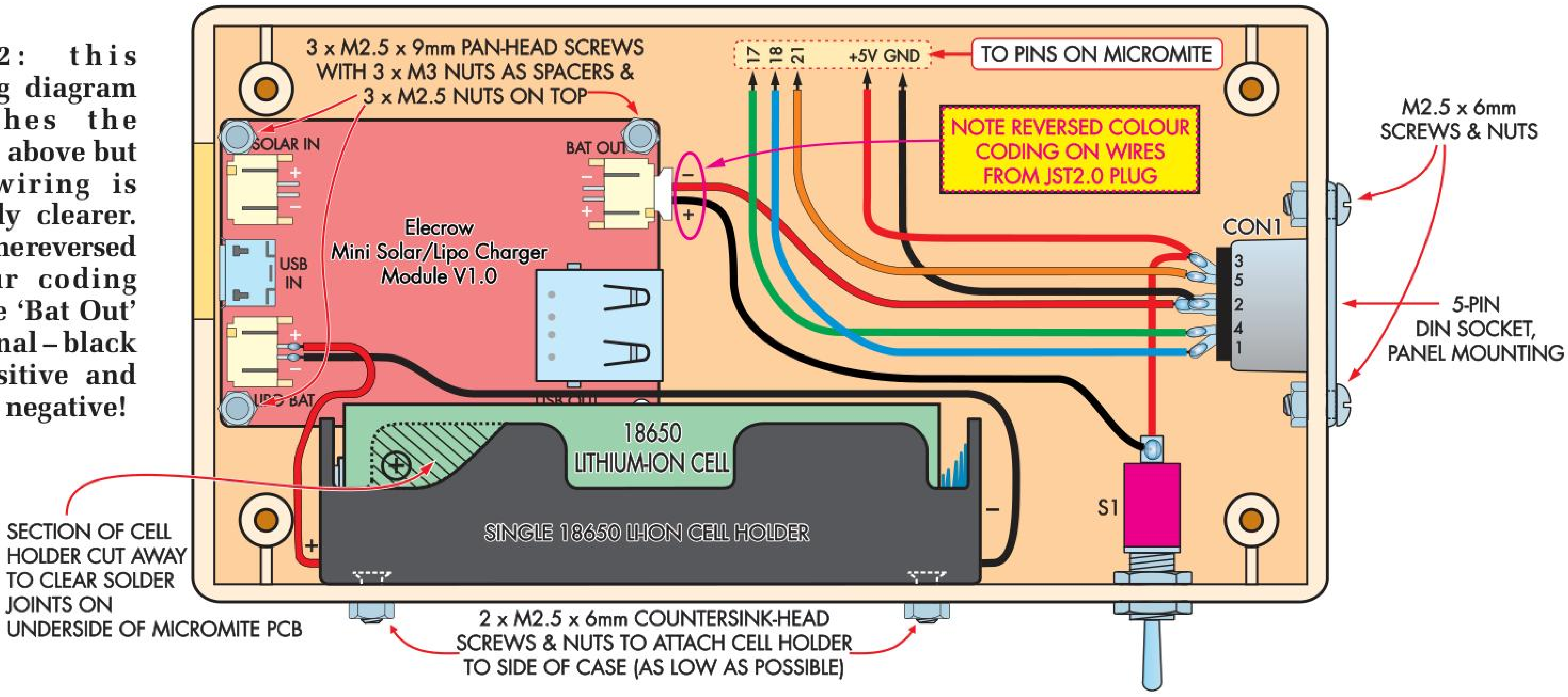
Next, cut off two sections of SIL header socket strip: one four-clips long, and the other three-clips long. After removing any burrs these are slipped over the 4-pin header on the barometer module and the 3-pin header on the AM2303 RH sensor module, ready for soldering the various wires from the connecting cable.

To prepare the cable itself, carefully remove about 50mm of the outer plastic sleeve from one end. Then peel back the metal screening foil and twist it together with the bare wire just inside it.

Strip away about 4-5mm of insulation from the ends of the main conductors. After these ends are tinned, all of the wires together with the screening foil and wire can be passed through the cable grip gland, until the end of the cable's outer sleeve is about 5mm past the inner end of the gland. Then the gland's outer nut can be tightened up to hold the cable in this position.

Then solder the various wires to their correct pins of the header sockets on the two modules. We suggest that you use the colour coding shown in Fig.3, to help avoid swapped connections.

Two small points to note: if the cable supplied has six wires instead of five,



3 x M2.5 x 9mm PAN-HEAD SCREWS WITH 3 x M3 NUTS AS SPACERS & 3 x M2.5 NUTS ON TOP
17
18
21
+5V GND
TO PINS ON MICROMITE
M2.5 x 6mm SCREWS & NUTS
SOLAR IN
BAT OUT
NOTE REVERSED COLOUR CODING ON WIRES FROM JST2.0 PLUG
USB IN
Elecrow Mini Solar/Lipo Charger Module V1.0
CON1
3
5
2
4
1
5-PIN DIN SOCKET, PANEL MOUNTING
LIPO BAT
USB OUT
18650 LITHIUM-ION CELL
SINGLE 18650 LI-ION CELL HOLDER
S1
SECTION OF CELL HOLDER CUT AWAY TO CLEAR SOLDER JOINTS ON UNDERSIDE OF MICROMITE PCB
2 x M2.5 x 6mm COUNTERSINK-HEAD SCREWS & NUTS TO ATTACH CELL HOLDER TO SIDE OF CASE (AS LOW AS POSSIBLE)

Fig.2: this wiring diagram matches the photo above but the wiring is slightly clearer. Note the reversed colour coding on the 'Bat Out' terminal – black is positive and red is negative!

Weatherproofing

Because the sensor unit (especially) would normally be used in the open air (where it can read temperature and pressure) we would be inclined to weatherproof it as much as possible, consistent with still being able to make reliable readings.

To protect them, a conformal coating, such as HK Wentworth's 'Electrolube HPA', could be sprayed on the underside of PCBs and also on any soldered joints. **Don't spray the top side of any of the modules!**

Errata: there is a discrepancy between the circuit diagram (Fig.1) and wiring diagram Fig.3). Some DHT22/AM2303 modules come attached to a small breakout board as shown in Cheap Electronic Modules, Part 4 (*EPE*, April 2018).

If using the breakout board, the 1kΩ resistor and 100nF capacitor shown in Fig.1 are not needed and the DHT22 can be wired to the DIN socket as shown in Fig.3. Otherwise, if your module comes with no breakout board, solder the resistor and capacitor as shown in Fig.1.

connect the 'extra' white wire to the same socket lugs as the black ground wire and the screening foil wire.

Also note that the red wire of the cable must connect to the VIN socket lug for the GY-68 module as well as the VCC lug for the AM2302 module, while the black wire must connect to the GND lugs for both modules. This will involve two short lengths (about 40mm) of insulated wire, ideally with red and black insulation respectively.

The internal wiring of the UB5 sensor unit should now be complete and you can fit the box lid. All that will then remain is to fit the 5-pin DIN plug to the other end of the cable.

To do this, first slip the plug's outer plastic sleeve over the end of the cable and out of the way. Then carefully remove about 15mm of the cable's outer sleeve from the end, and as before, peel back the screening foil and twist it together with the bare earthing wire. Then strip away about 5mm of the insulation from each of the inner wires.

Next, twist the ends of the black and white wires together, and lightly tin the ends of all bared wires before soldering them to the rear of each of the plug's pins.

As shown in Fig.3, the blue wire solders to pin 1, the green wire to pin 4, the black/white/screen wires all to pin 2, the orange wire to pin 5 and the red wire to pin 3.

When you're happy with these connections, squeeze together the cable grip lugs on the rear of the lower part of the plug shell using a pair of pliers, so that they will hold the cable in position.

Then fit the upper half of the shell and slide the plug's outer plastic sleeve back up the cable and over the plug's metal shell, to hold it all together.

Main unit assembly

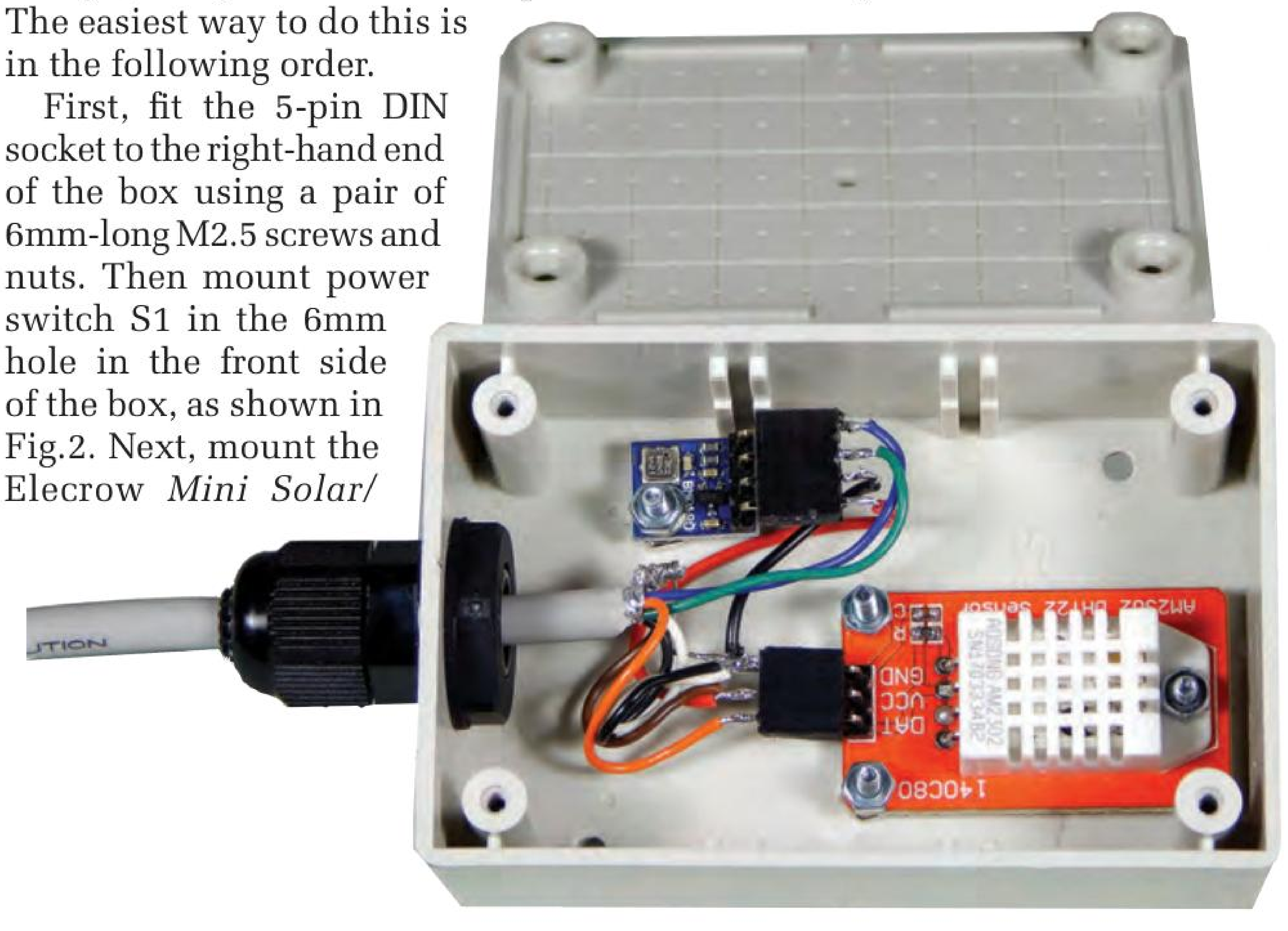
Most of the information you'll need to assemble everything in the UB3 main unit box can be found in the diagrams of Fig.2, along with the internal photo. The easiest way to do this is in the following order.

First, fit the 5-pin DIN socket to the right-hand end of the box using a pair of 6mm-long M2.5 screws and nuts. Then mount power switch S1 in the 6mm hole in the front side of the box, as shown in Fig.2. Next, mount the Elecrow *Mini Solar/LiPo Charger* module in the bottom of the left-hand end of the box, using three 9mm-long M2.5 screws and nuts, together with three M3 nuts as spacers. The module should be mounted with the USB micro input socket end to the left, just inside the stepped access hole.

Slide the Li-Ion cell holder down inside the front of the box as far as it will go, oriented as shown in Fig.2. This should allow you to mark the location of the two holes which need to be drilled in the bottom of the holder, to match the holes already drilled in the box. You should be able to mark the hole locations using a small scriber or needle.

Then remove the cell holder again, so that you can easily drill a 2.5mm hole in each of the two marked positions. After drilling, remove any burrs with a larger drill or countersink, and if you can manage it, also countersink both holes on the inside of the holder. If you slide the prepared holder back down into the box, you should then be able to fasten it in position using two 6mm-long countersink-head M2.5 screws and nuts – with the nuts on the outside as indicated in Fig.2.

When the holder is in place, you need to use a sharp knife or rotary tool to cut away a section of the left-hand



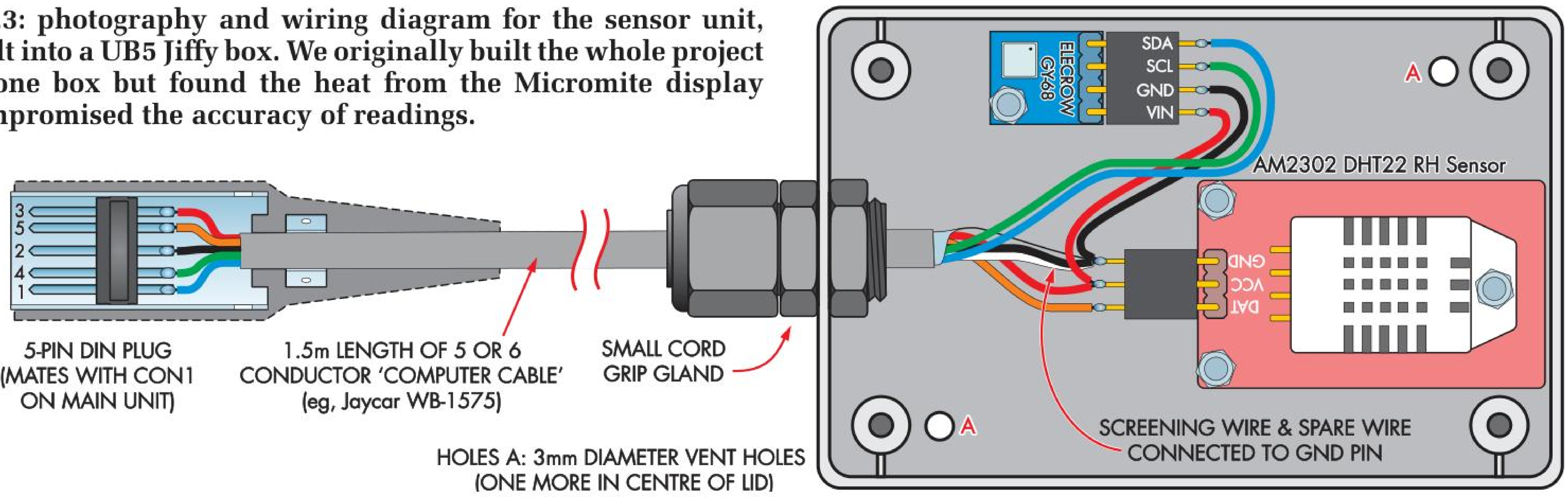

3
5
2
4
1
5-PIN DIN PLUG (MATES WITH CON1 ON MAIN UNIT)
1.5m LENGTH OF 5 OR 6 CONDUCTOR 'COMPUTER CABLE' (eg, Jaycar WB-1575)
SMALL CORD GRIP GLAND
HOLES A: 3mm DIAMETER VENT HOLES (ONE MORE IN CENTRE OF LID)
ELECROW GY68
SDA
SCL
GND
VIN
A
AM2302 DHT22 RH Sensor
GND
VCC
DAT
A
SCREENING WIRE & SPARE WIRE CONNECTED TO GND PIN

Fig.3: photography and wiring diagram for the sensor unit, built into a UB5 Jiffy box. We originally built the whole project in one box but found the heat from the Micromite display compromised the accuracy of readings.

upper 'wing' of the holder, as indicated by the cross-hatched area in Fig.2. This is to prevent it from interfering with some solder joints on the underside of the *Micromite BackPack* PCB, on the latter's front left. You can also see this in the internal photo.

Solder the ends of the Li-Ion cell holder's leads to the rear lugs of the JST2.0 socket on the *Charger* module, after cutting each one to an appropriate length and stripping and tinning about 4mm from the end of each wire. The red wire should be soldered to the lug marked '+', and the black wire to the lug marked '–'.

Next, connect the two wires from the JST2.0 plug lead connected to the socket on the *Charger* module labelled 'BAT OUT', to their designated locations. Note that since many of these plug leads have reversed colour coding, the black positive wire should be connected to the uppermost lug of S1, while the red negative wire connects to pin 2 of CON1.

All that remains is to add the rest of the wiring, using Fig.2 and the internal photo as a guide.

Note that the three wires from CON1 which are marked as connecting to pins 17, 18 and 21 of the Micromite should be soldered at their upper ends to the lugs of a 3-way section of SIL socket strip, while the wires marked +5V and GND should be soldered to a 2-way section of the same socket strip. Both sections of socket strip will then be ready to connect to the corresponding pins of the Micromite.

The next step is to mount the *Micromite BackPack* and its LCD touchscreen to the underside of the box lid, or to the replacement laser-cut acrylic lid/panel if you are using this. Just before you do this, however, you may want to attach the front panel artwork shown in Fig.7 to the lid/panel, to make it look more professional.

For more information on assembling and using the *TouchScreen Micromite BackPack*, refer to the articles in the May 2017 and May 2018 issues of *EPE*.

You can see how the *BackPack* and LCD is attached to the rear of the lid/front panel in Fig.6.

The LCD board is attached directly to the panel using four 10mm-long M3 machine screws, with 1mm-thick nylon flat washers as spacers and four M3 × 12mm-long tapped nylon spacers underneath as 'long nuts'. Then the *Micromite BackPack* PCB is attached to the lower ends of the tapped nylon spacers, using only three 6mm-long M3 machine screws.

No screw is used in the front left position, because if fitted the head of this screw would conflict with the top of the Li-Ion cell holder during final assembly.

Note that all connections between the *Micromite BackPack* PCB and the LCD board above it are made via a 14-way SIL header and socket at their right-hand ends.

Once the Micromite and LCD boards are secured to the underside of the front panel, you're almost ready for final assembly of the main unit.

Only two items remain: slipping the 18650 Li-Ion cell into its holder (making sure that its positive end is to the left) and then fitting the 3-way and 2-way SIL sockets on the wires from the 5-way DIN socket to the correct pins along the rear of the Micromite PCB.

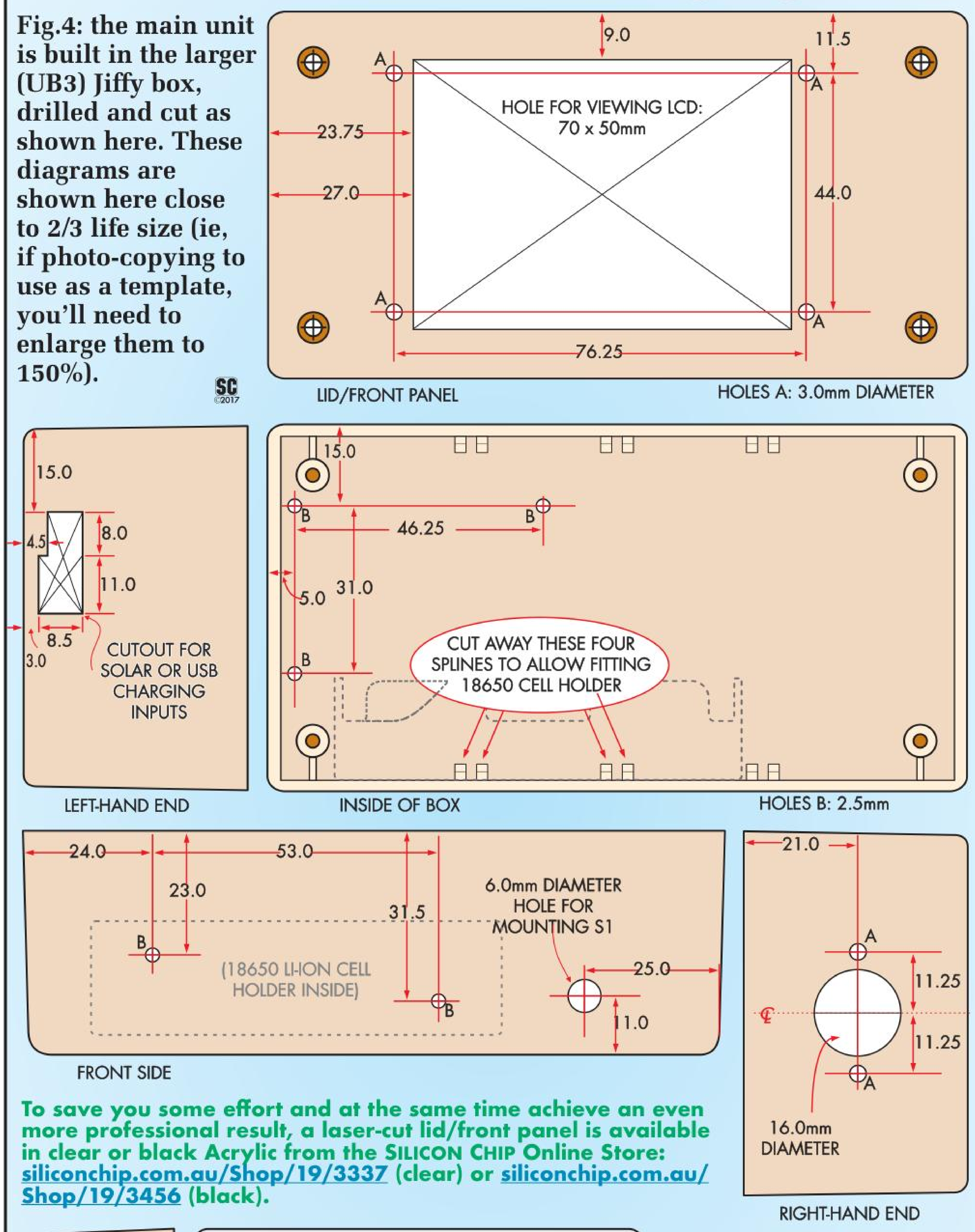
Now plug the cable from the sensor unit into CON1, so the two units are linked together.

Programming the firmware

Your *Touchscreen Altimeter* is now virtually complete but you need to download the project's firmware program from the *EPE* website, and then upload it to the Micromite.

The firmware for this project is called **Altimeter.bas** and the next step is to connect the Micromite in your *Altimeter/Weather Station* to a USB port of your PC, either directly in the

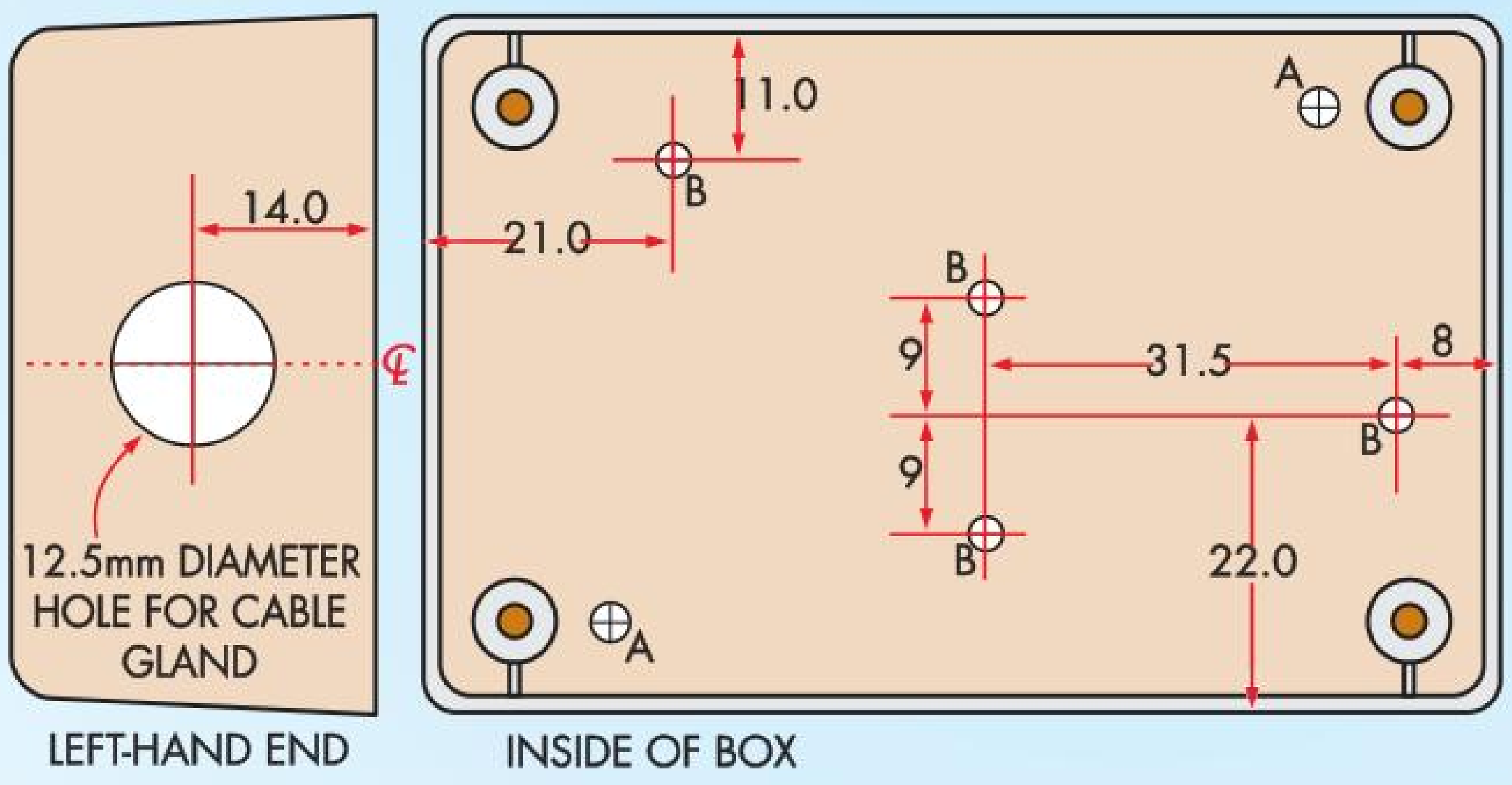
Main unit and sensor unit drilling diagrams



9.0
11.5
A
HOLE FOR VIEWING LCD: 70 x 50mm
23.75
27.0
44.0
76.25
LID/FRONT PANEL
HOLES A: 3.0mm DIAMETER
SC ©2017
15.0
4.5
8.0
11.0
8.5
3.0
CUTOUT FOR SOLAR OR USB CHARGING INPUTS
LEFT-HAND END
B
46.25
5.0
31.0
CUT AWAY THESE FOUR SPLINES TO ALLOW FITTING 18650 CELL HOLDER
INSIDE OF BOX
HOLES B: 2.5mm
24.0
53.0
23.0
31.5
(18650 LI-ION CELL HOLDER INSIDE)
6.0mm DIAMETER HOLE FOR MOUNTING S1
25.0
11.0
FRONT SIDE
21.0
11.25
℄
16.0mm DIAMETER
RIGHT-HAND END

Fig.4: the main unit is built in the larger (UB3) Jiffy box, drilled and cut as shown here. These diagrams are shown here close to 2/3 life size (ie, if photo-copying to use as a template, you'll need to enlarge them to 150%).

To save you some effort and at the same time achieve an even more professional result, a laser-cut lid/front panel is available in clear or black Acrylic from the SILICON CHIP Online Store: siliconchip.com.au/Shop/19/3337 (clear) or siliconchip.com.au/Shop/19/3456 (black).



14.0
℄
12.5mm DIAMETER HOLE FOR CABLE GLAND
LEFT-HAND END
11.0
A
B
21.0
9
31.5
8
22.0
INSIDE OF BOX

Fig.5 (left): the sensor unit is built in a smaller UB5 Jiffy box, drilled as shown here.

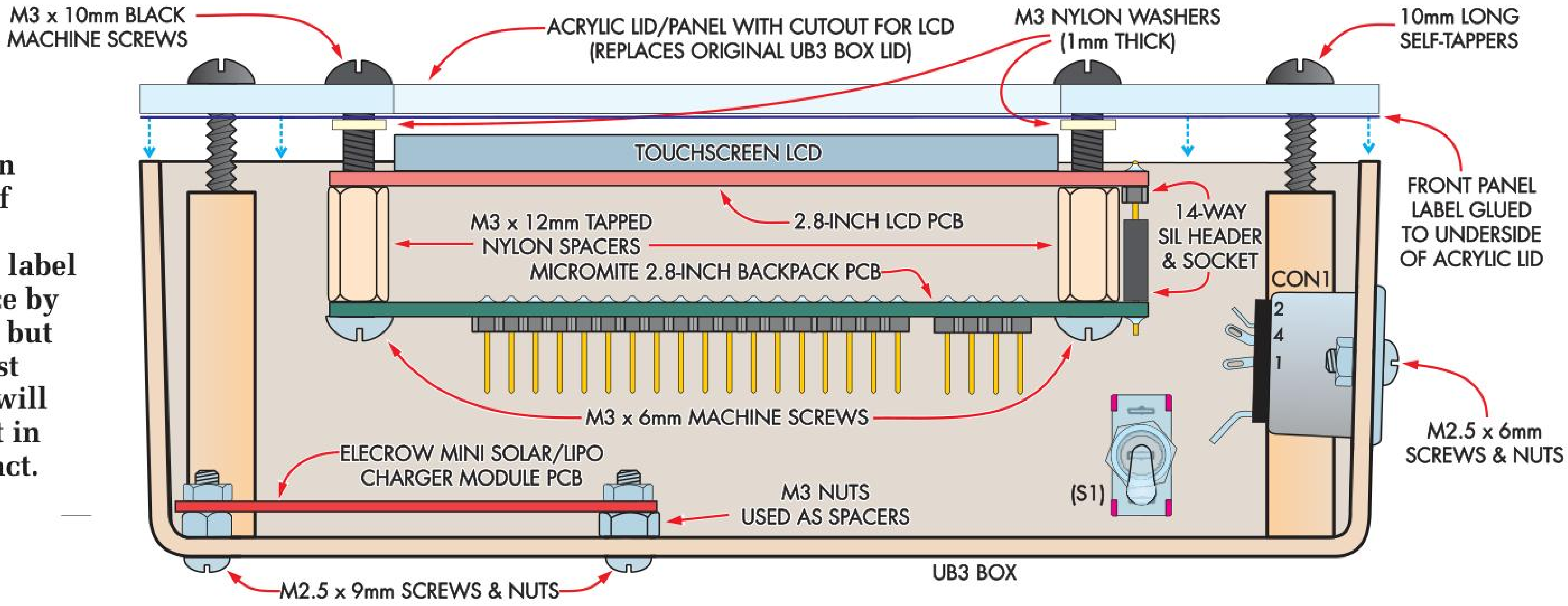

M3 x 10mm BLACK MACHINE SCREWS
ACRYLIC LID/PANEL WITH CUTOUT FOR LCD (REPLACES ORIGINAL UB3 BOX LID)
M3 NYLON WASHERS (1mm THICK)
10mm LONG SELF-TAPPERS
TOUCHSCREEN LCD
FRONT PANEL LABEL GLUED TO UNDERSIDE OF ACRYLIC LID
M3 x 12mm TAPPED NYLON SPACERS
2.8-INCH LCD PCB
14-WAY SIL HEADER & SOCKET
MICROMITE 2.8-INCH BACKPACK PCB
CON1
2
4
1
M3 x 6mm MACHINE SCREWS
M2.5 x 6mm SCREWS & NUTS
ELECROW MINI SOLAR/LIPO CHARGER MODULE PCB
M3 NUTS USED AS SPACERS
(S1)
UB3 BOX
M2.5 x 9mm SCREWS & NUTS

Fig.6: a side-on 'X-ray' view of the main unit assembly. The label is held in place by the acrylic lid but a very fine mist of spray glue will help to keep it in intimate contact.

case of a Micromite v2, or via a USB/UART bridge module in the case of a Micromite v1.

Either way, we suggest that you start up Control Panel>Device Manager to make sure that the Micromite has been recognised as a virtual COM port and to take note of the COM port number and baud rate it has been allocated.

Now you should be able to start up the MMEdit program and use it to open the downloaded **Altimeter.bas** program.

Then, after making sure that MMEdit can communicate with the Micromite in the *Altimeter/WeatherStation*, it's just a matter of getting it to upload the program and then set it running.

Since the programming connection to the PC also provides power, you should find that the *Altimeter/Weather-Station* springs to life as soon as the program is set running.

You should see the display on the LCD showing the altitude, air temperature, the relative humidity, the barometric air pressure (see photo of the *Weather Station* display).

If all is well so far, the programming cable can be disconnected from the Micromite.

The display will probably go dark again, unless your have turned on power switch S1 and your Li-Ion cell has some initial charge.

Now the front panel assembly can be gently lowered into the box and the four small 10mm long self-tappers used to fasten the two together.

Your *Altimeter/Weather Station* should now be complete and ready to go. Charge the Li-Ion cell for a few hours (via a USB cable, power supply or solar panel) before you turn on S1 again to put the project to work.

What it can do

When you turn it on for the first time, you should get the *Weather Station* display shown in the photos. The device will initially start up in this mode, and will also have its altitude reference set to MSL (mean sea level) and the altitude units set to metres – as indicated in the line of text just below the Altitude reading.

At the bottom of the display you'll see a red button labelled 'TOUCH TO CHANGE MODE OR UNITS'. And if you do touch this button, the display will change into a one giving you the options of changing to the alternative *Altimeter* display, changing the altitude units to feet instead of metres (or back again), or changing the altitude reference level from MSL to the current ground level (or back again). There's also an 'EXIT WITHOUT ANY CHANGES' button at the bottom of this screen.

So if you want to change over to *Altimeter* mode, this is done quite simply by touching the button at upper right, labelled 'ALTIMETER MODE'. This will change the display over to one showing just the altitude, in large digits for high visibility. But the altimeter units and reference level won't have changed at this stage, so the text just below the altitude digits will still read 'metres above MSL'.

If you're happy with these settings, fine. But if you'd rather have the altitude in feet rather than metres, simply touch the button at the bottom of the screen to bring up the 'change options' display again.

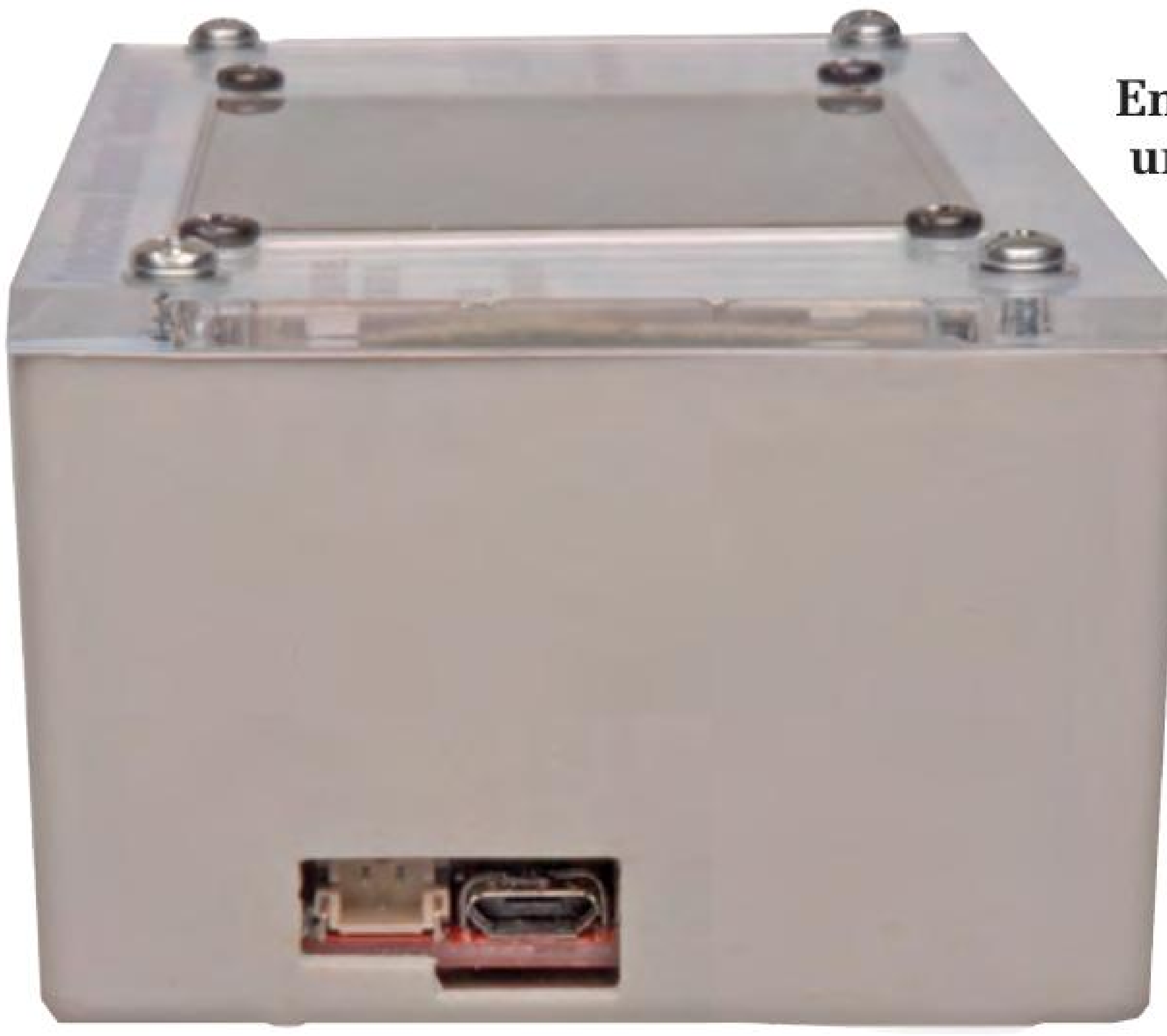
Then touch the button labelled 'FEET', and you'll return to the *Altimeter* screen displaying feet rather than metres.

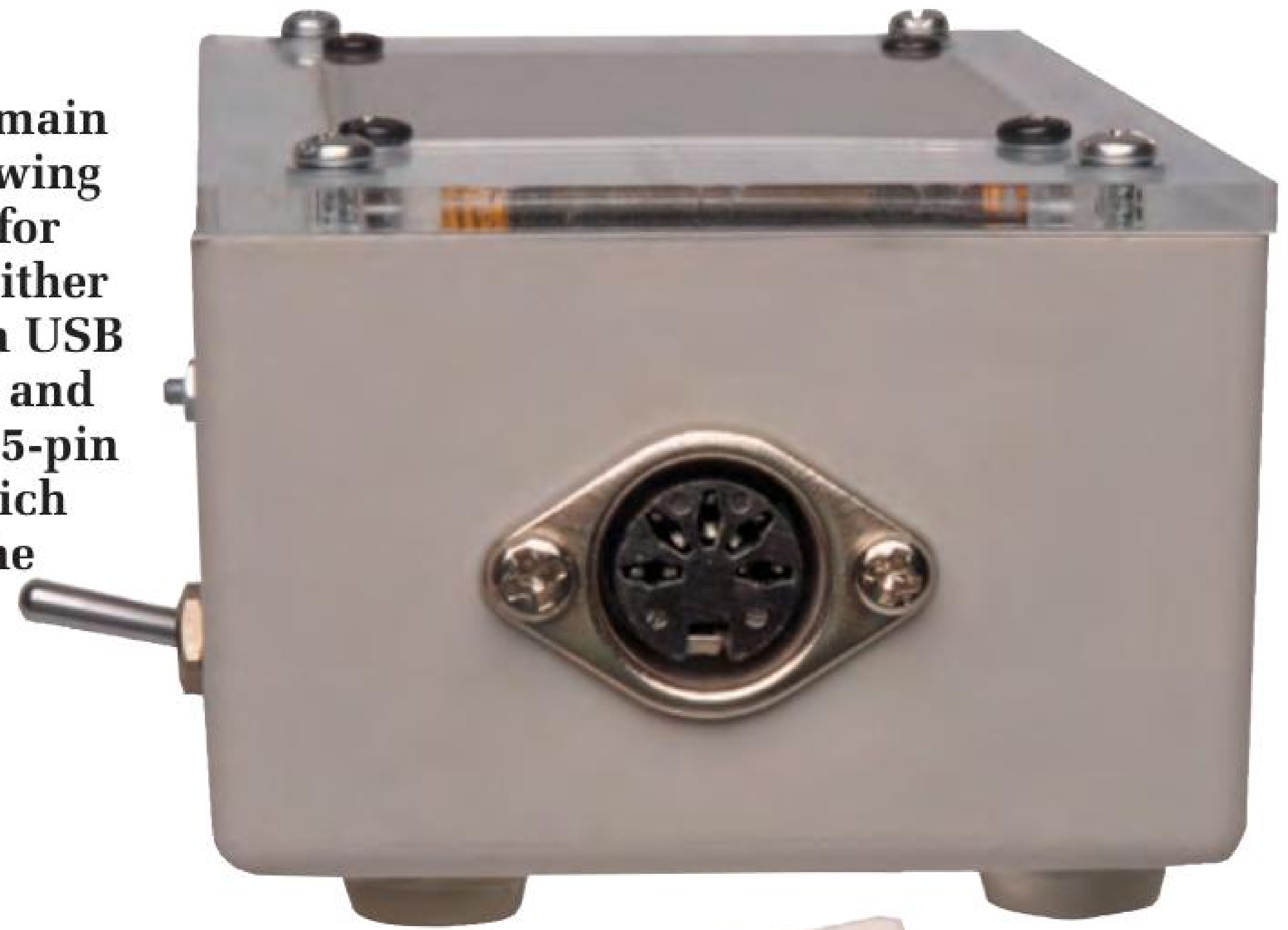
Here's an important point to note, though. If the altitude reference level is still set to MSL, you may be getting a negative altitude reading if the air pressure in your vicinity happens to be significantly higher than the nominal MSL level of 1013.25hPa (hectopascals).

Parts list – Touchscreen Altimeter and Weather Station

1	UB3 jiffy box (130 × 68 × 44mm)
1	laser-cut acrylic front panel to suit above #
1	front panel label to suit ^
1	UB5 jiffy box (83 × 54 × 31mm)
1	Micromite LCD BackPack (v1 or v2) + 2.8-inch LCD §
1	Elecrow GY-68 barometer/altimeter module §
1	DHT22/AM2302 temperature/RH module §
1	Elecrow mini LiPo/Li-Ion charger module
1	**1kΩ resistor and 1 100nF ceramic capacitor if not using a DHT22 with breakout board**
1	18650 rechargeable Li-Ion cell
1	1 × 18650 Li-Ion cell holder
1	SPDT mini toggle switch
1	5-pin DIN socket, panel mounting
1	5-pin DIN plug, inline type
1	1.5m length of 5/6-way screened 'computer' cable
1	3-6.5mm cable gland
7	M2.5 × 8mm pan head machine screws and nuts
7	M3 hex nuts
2	M2.5 × 6mm pan head screws and nuts
5	M3 × 6mm pan head machine screws
1	16-way female header (to cut into 1 × 4-way, 2 × 3-way and 1 × 2-way)
4	M3 × 10mm long machine screws
4	M3 Nylon flat washers
4	12mm long M3 tapped nylon spacers
2	M2.5 × 6mm countersink head screws and nuts
1	120mm length of rainbow ribbon cable (to make interconnections)

# Available from the Silicon Chip shop
^ Download from EPE website
§ From micromite.org (Micromite with software preload option)





End-on views of the main unit (left photo) showing the connections for power in, from either a solar panel or a USB supply/PC port; and (right photo) the 5-pin DIN socket which connects to the sensor unit.

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The three mounting screws for the Elecrow *Charger* PCB and the 5-pin DIN socket on the end. The 18650 cell holder mounts on the side wall of the case (see nuts).

This can be a bit confusing, but the problem is easily fixed by touching the button at the bottom of the screen once again, and then touching the 'GROUND REFERENCE' button at lower right on the 'change settings' display.

This will set the altitude reference level to the current barometric pressure level; ie, the altitude at your current position.

This 'ground reference level' can be reset at any time, simply by switching to the 'change settings' display and touching the 'GROUND REFERENCE' button again.

By the way, whenever you change any of the settings in the 'change settings' display, all of the setting parameters are saved in the Micromite's non-volatile memory. This means that if you turn off the device power, next time you power it up again the same settings will be restored.

You can always change back from *Altimeter* mode to *Weather Station* mode, simply by touching the button at the bottom of the screen and then the 'WEATHER STN MODE' button at upper left.

Similarly, you can change the altimeter units to metres and the altimeter reference level back to MSL.

One last point: as mentioned earlier, when fully charged, a single 18650 Li-Ion cell of decent quality should be able to power the *Altimeter/Weather Station* for between 3.8 and 8.75 hours. This should be long enough for most purposes, but don't forget to charge it up before going on a flight or journey.

When the cell's voltage falls to where it's no longer capable of powering the unit, you'll notice the display flickering. Time to turn it off and charge it!

Micromite parts

We strongly recommend you make **micromite.org** your first port of call when shopping for all Micromite project components. Phil Boyce, who runs micromite.org, can supply kits, programmed ICs, PCBs and many of the sensors and other devices mentioned in recent articles – in fact, just about anything you could want for your Micromite endeavours. Phil works closely with Geoff Graham and is knowledgeable about the whole series of Micromite microcontrollers.

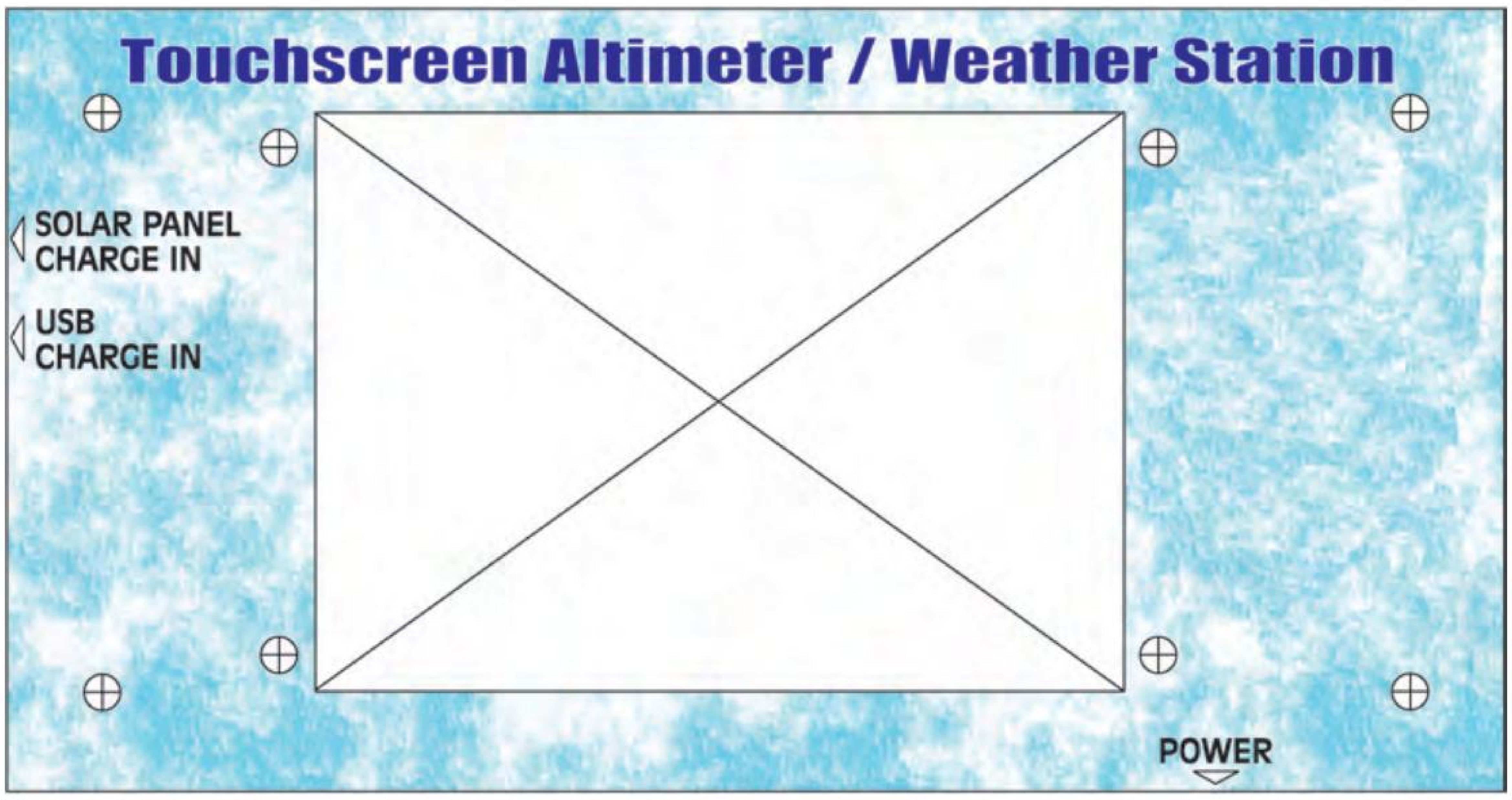
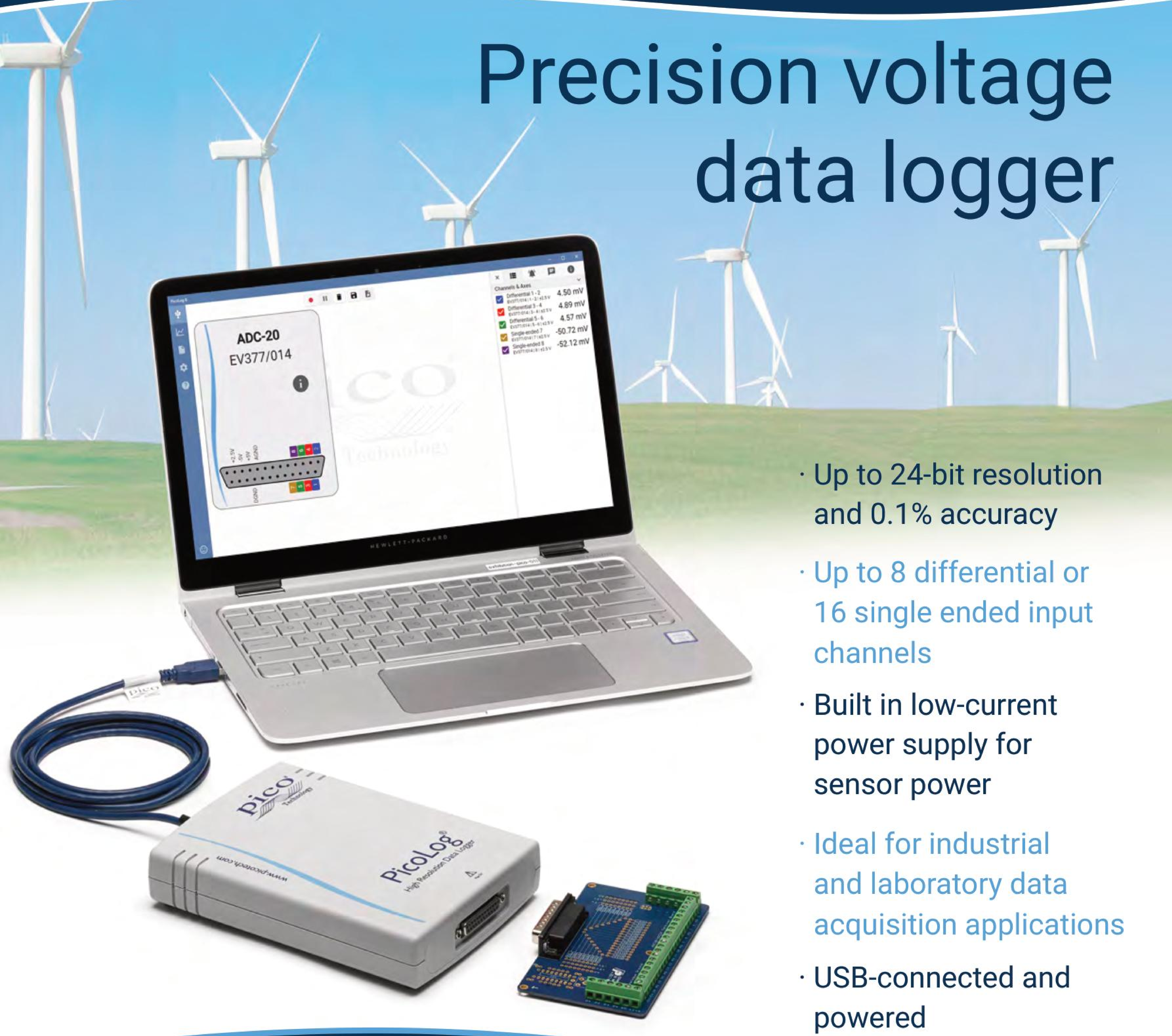


Fig.7: a full-size front panel artwork for the *Altimeter/Weather Station*, ready to photocopy (or download from the *EPE* website. We printed ours on heavy, glossy photographic paper. The idea is that this label is mounted behind, and visible through, the clear acrylic laser-cut front panel, so it is fully protected from, especially, the weather (and grubby fingers!). This label will normally be held in place by the front panel; however, a *very* fine dusting of spray adhesive will hold it in position while you drill the label holes (all 3mm) and cut out the *Touchscreen Display* rectangle with a very sharp hobby knife.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The Pro Evaluation Kit supports all SAM L10/11 MCUs by the Atmel Studio 7 IDE (integrated development environment), IAR Embedded Workbench, Arm Keil MDK, as well as the Atmel START. Microchip's QTouch Modular Library, 2D Touch Surface Library and QTouch Configurator are also available to simplify touch development.

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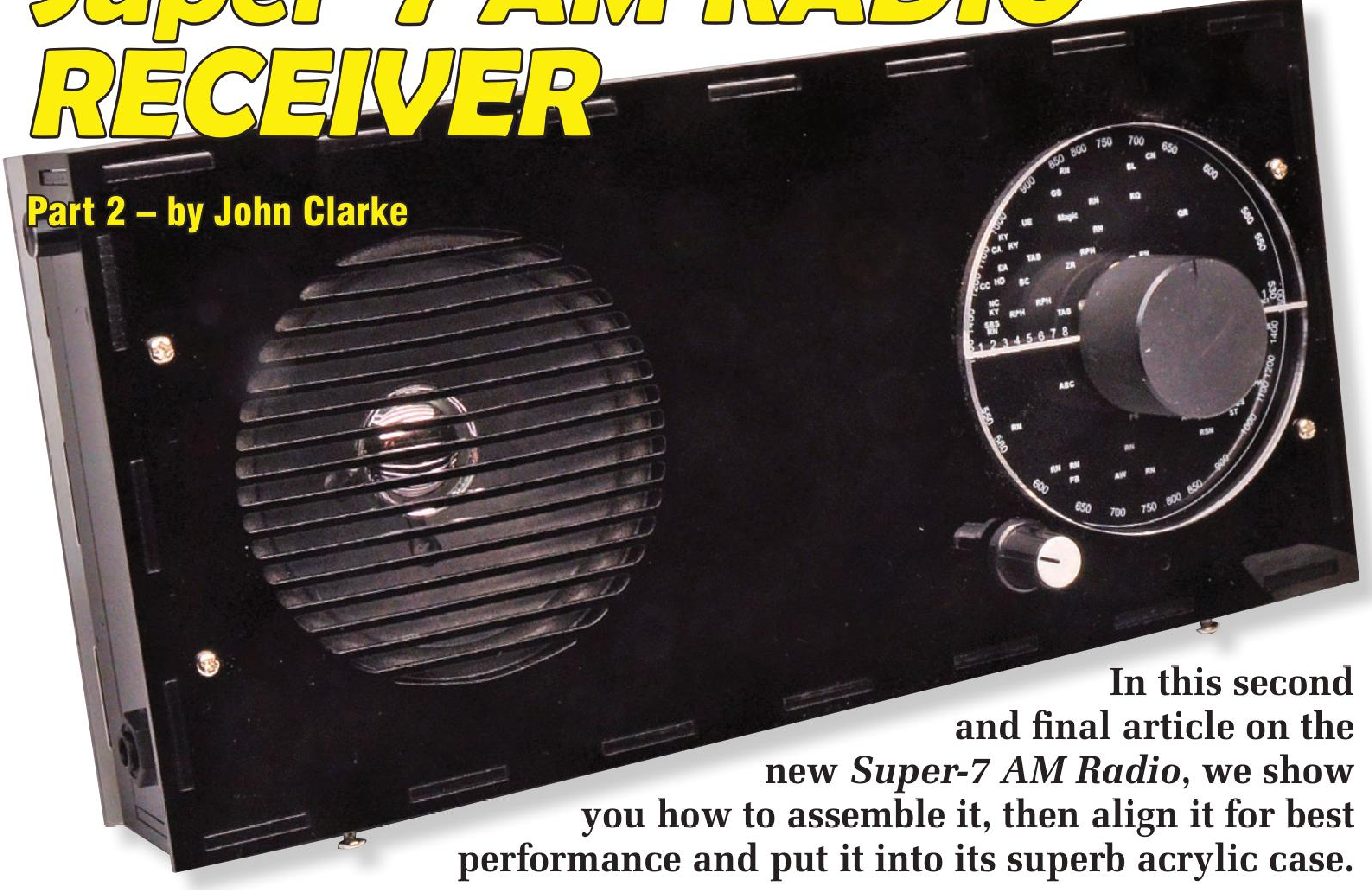
They each won an AVR Dragon Debugger, valued at £26.25 each

Super-7 AM RADIO RECEIVER

Part 2 – by John Clarke



In this second and final article on the new *Super-7 AM Radio*, we show you how to assemble it, then align it for best performance and put it into its superb acrylic case.

Assembly is not at all difficult – everything is mounted on one large PCB and we don't use any SMD components – so it's standard soldering all the way.

And don't be put off by alignment: it's not hard to do and can be done using quite basic equipment, as we will explain shortly.

Of course, it can also be even better using specialised equipment, such as the *Dead-Easy DDS Superhet IF Alignment Unit* we published in the September 2018 issue.

As its name suggests, this makes alignment, or adjustment of the IF coils, on the *Super-7 AM Radio* . . . dead easy! (see the panel at the end of the article).

But if you can't justify building a device such as this, there are other ways to do it; maybe not quite so simple or elegant, but effective nevertheless. We will cover other approaches to align the radio set shortly.

There are a number of test points on the circuit board which can be used for voltage measurements or to provide signals to be displayed on an oscilloscope. We will show some typical waveforms in this article, so you will know what to expect.

Fortunately, you don't need an expensive 'scope for this – indeed, there are any number of 1MHz bandwidth kit models available on ebay and similar (ie, you build them first!) for well under £50.

And if you're at all into hobby electronics you really do need an oscilloscope on your bench. Spend a little more and you can get a really good, higher bandwidth scope which will suit your needs for many years.

Construction

The *Super-7 AM Radio* is built on one double-sided PCB coded 06111171 and measuring 313 × 142.5mm.

It is housed in a multi-piece acrylic case, available from the SILICON CHIP Online Shop. This also includes a transparent tuning dial. Station call signs (eg, RN for Radio National) and frequency markings that are screen-printed on the PCB can be seen through it. (*Do note that the text is only relevant for Australian users.*)

The *Super-7 AM Radio* uses some special AM radio parts. These include a coil pack, a mini tuning gang capacitor and ferrite rod with coil. Otherwise, most of the parts are pretty common – you may have many of them in your 'junk' box.

Fig.1, the circuit, was published last month. Fig.2 (overleaf) is the overlay diagram and this shows where all the components go on the PCB. Use this (and the photos) as a reference while following these instructions to fit the components to the board.

Begin construction by installing the resistors. We suggest that you also check each resistor value with a digital multimeter before it is inserted – some colour bands appear close to others (eg, red, brown and orange) so it is always wise to double check, especially before you solder them in.

Resistors are not polarised – they can be inserted either way into the board, but it is a good idea to install them so that their colour codes all align in the same direction. This makes it so much easier to check their values later on.

Fit the PC stakes for the GND (TP GND), two near CON2 (for the speaker), one at TP1 and five for VR1. Three of the PC stakes for VR1 are to wire it to the board, while the remaining two are to solder to the potentiometer body to hold it more securely. This pot is installed later.

Next, install the capacitors. There are three types used in the circuit. One type is MKT polyester (plastic) and these can be recognised by their rectangular shape. These are not polarised. The second type is ceramic and these are also not polarised. They are all the same value, so you can't get them mixed up.

The third type of capacitors used in this project are electrolytics – they *are* polarised and must be inserted the right way around – follow the markings on the PCB overlay. Electrolytics are (usually) cylindrical in shape, with a polarity stripe along one side for the negative lead. The opposite (positive) lead is usually the longer of the two.

Almost invariably, electrolytic capacitors will have their actual value printed on them, along with their voltage rating.

One point which may confuse beginners: it is normally OK to use an electrolytic capacitor (or indeed any capacitor) with a voltage rating higher than that specified, as long as there is room (capacitor size normally increases with voltage). However, it is **not OK** to use capacitors with a lower voltage rating than that specified.

For example, if a circuit calls for a 10µF, 16V electrolytic capacitor, you can normally use one of the same value and type – 10µF electrolytic – with a 25V, 35V or even higher rating, as long as it will fit. However, you generally *cannot* use a 10µF electrolytic capacitor with a 6.3V rating – it is liable to explode! But in this circuit, you could use capacitors with a 10V rating, since the battery voltage is only 9V.

OK, back to construction: install diodes D1, D2 and D3. While they may look identical, each diode is a different type so don't mix these up. Diodes are also polarised. The polarity band or stripe, which indicates the cathode (k), is oriented toward the bottom of the PCB as shown on the overlay diagram.

The transistors go in next. Again, make sure you put the correct transistor in each position. Transistors Q6 and Q7 are mounted horizontally with leads bent over at 90° so that their holes line up with the holes in the PCB.

The Q6 and Q7 transistor bodies are attached to the PCB with M3 × 10mm screws and nuts with the screw placed from the rear of the PCB and the nut on the transistor. (The copper of the PCB acts as a 'heat sink' to keep them from overheating).

The remaining transistors don't handle as much power so they are smaller types which are mounted vertically on their leads. You may need to splay their leads out to fit the mounting holes on the board (eg, using small pliers). Make sure the 'D'-shaped packages (looking down on them) go the same way around as shown on the overlay diagram.

IF transformers

Now you can install the oscillator and IF transformers. They will only go in one way, with three pins on one side and two on the other. However, these all look the same except for the colour of the slug at the top. The colours are as follows: the oscillator transformer (T2) is red; both the (identical) IF transformers (T3 and T4) are white; the third IF transformer (T5) is black. The mounting positions for each of these transformers are clearly indicated on the PCB.

By the way, resist the temptation to twiddle the slugs of the IF transformers and oscillator coil, especially using a small screwdriver. There are several reasons not to use a small screwdriver to adjust the slugs.

First, it is all too easy to crack the slug since these are brittle and once broken will be jammed in the transformer core.

Second, the blades of screwdrivers are often magnetised and this can affect the magnetic characteristics of the slugs.

Third, when you are aligning the radio, the steel blade of the screwdriver will affect the resonance of the coil and you will get misleading results.

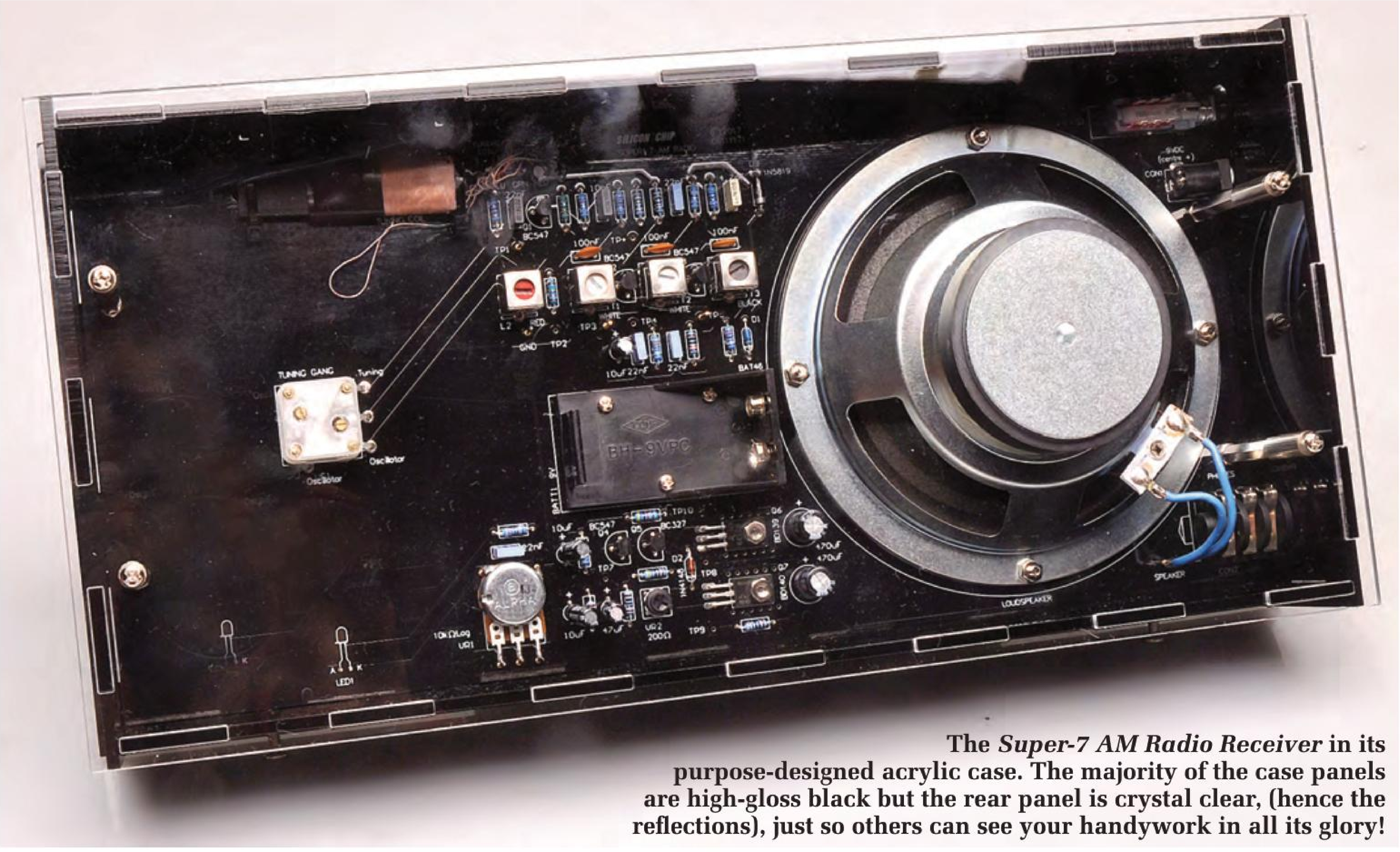
You should use a set of plastic alignment tools (they're quite cheap) and use one which has a blade that's a neat fit in the slot of the slug.

If you can't purchase a suitable alignment tool, you can make one out of a piece of scrap plastic shaped at one end so that it is like a screwdriver blade and sized to neatly fit the slug slot. You can easily do this with a sharp utility knife and needle files. Many a plastic knitting needle has disappeared from mum's sewing basket over the years to make alignment tools!

When installing the ferrite rod antenna, secure the ferrite rod in place with cable ties, but keep them loose for the moment, as you will need to adjust the coil position later during alignment.

The coil on the ferrite rod has four very fine cotton-covered coloured wires. Keep these the length that they are, ie, do not cut them short, since they are already pre-tinned.

The circuit board connections for the antenna coil connections are labelled



The *Super-7 AM Radio Receiver* in its purpose-designed acrylic case. The majority of the case panels are high-gloss black but the rear panel is crystal clear, (hence the reflections), just so others can see your handywork in all its glory!

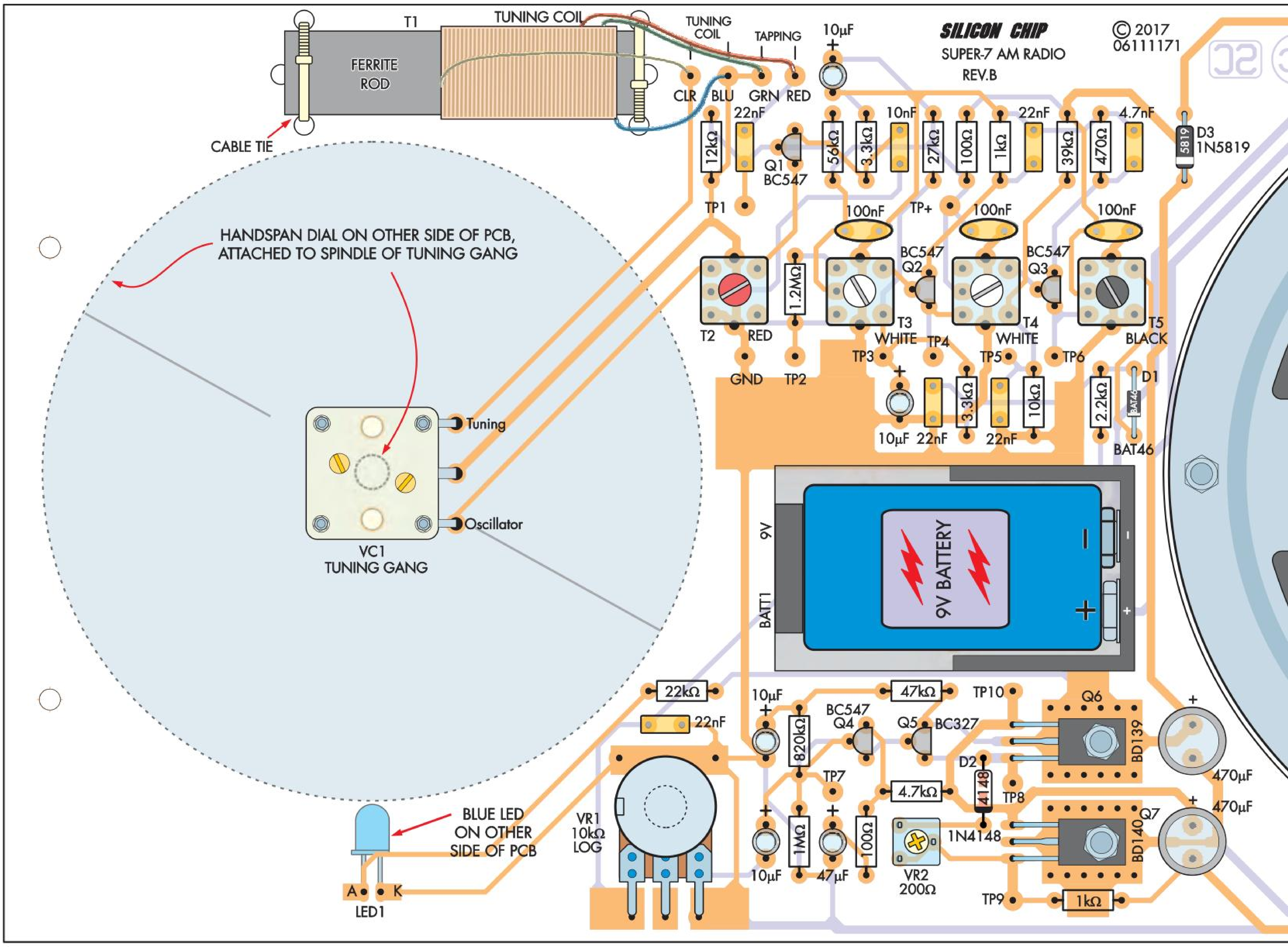

T1
TUNING COIL
FERRITE ROD
CABLE TIE
TUNING COIL
TAPPING
CLR
BLU
GRN
RED
10µF
SILICON CHIP
SUPER-7 AM RADIO
REV.B
© 2017
06111171
22nF
12kΩ
Q1
BC547
56kΩ
3.3kΩ
10nF
27kΩ
100Ω
1kΩ
22nF
39kΩ
470Ω
4.7nF
D3
1N5819
5819
TP1
100nF
TP+
100nF
100nF
HANDSPAN DIAL ON OTHER SIDE OF PCB, ATTACHED TO SPINDLE OF TUNING GANG
1.2MΩ
BC547
Q2
BC547
Q3
T2
RED
T3
WHITE
TP4
T4
WHITE
T5
BLACK
TP3
TP5
TP6
GND
TP2
D1
3.3kΩ
10kΩ
2.2kΩ
BAT46
10µF
22nF
22nF
BAT46
Tuning
Oscillator
VC1
TUNING GANG
9V
BATT1
9V BATTERY
22kΩ
10µF
47kΩ
TP10
Q6
22nF
820kΩ
BC547
Q4
Q5
BC327
D2
BD139
470µF
TP7
4.7kΩ
4148
TP8
470µF
Q7
BLUE LED ON OTHER SIDE OF PCB
VR1
10kΩ
LOG
1MΩ
100Ω
1N4148
BD140
A
K
LED1
10µF
47µF
VR2
200Ω
TP9
1kΩ

Fig.2: this PCB overlay diagram shows where to fit the components onto the board before soldering. Ensure polarised components (diodes, electrolytic capacitors and transistors) are the right way around. Also pay careful attention to ensure each component installed is of the correct value and type. The four transformers have colour coded slugs, as shown.

with the colours: clear (CLR), black (BLK), red (RED) and green (GRN). The clear wire is the one that is at the far end of the coil and is separate from the remaining three wires.

The plastic dielectric tuning capacitor (or tuning 'gang') is normally supplied with two tiny M3 screws which are used to secure it to the PCB. After these are inserted and tightened, the three tags need to be bent at right angles to insert into the holes on the PCB. They are then soldered in place.

You'll need a hacksaw to cut the volume control potentiometer shaft to 17mm in length (from where the threaded boss starts). There is a small location spigot on the side of the pot, which is not needed, so it can be snapped off with a pair of pliers or cut off with sidecutters.

We want to solder the pot body to the PC stakes to hold it securely in place, but the body is normally 'passivated' to prevent corrosion. This makes it almost impossible to solder – so you will need to scrape the pot sides with a hobby knife to remove some of the passivation before soldering.

Pass the potentiometer through the PCB from the component side and secure it with its washer and nut on the 'top' or label side. Bend the tags so that they touch the PC stakes on the board and solder them in place.

Trimpot VR2, for the audio amplifier output biasing, can also be installed at this stage, followed by the battery holder, on/off switch and headphone socket. The battery holder is held in place with self-tapping screws. The power switch and headphone socket are mounted directly on the board.

Speaker mounting

The speaker is fastened directly to the PCB using four M3 screws and nuts, with short lengths of hookup wire between the loudspeaker and speaker PC stakes. Note that there are eight speaker mounting holes, two sets of four on two different circumferences. So select the correct holes for your particular loudspeaker and orient it so the terminals are nearest to CON2.

Now check all your work very carefully and you will be ready for the next stage, which is alignment.

Aligning your radio

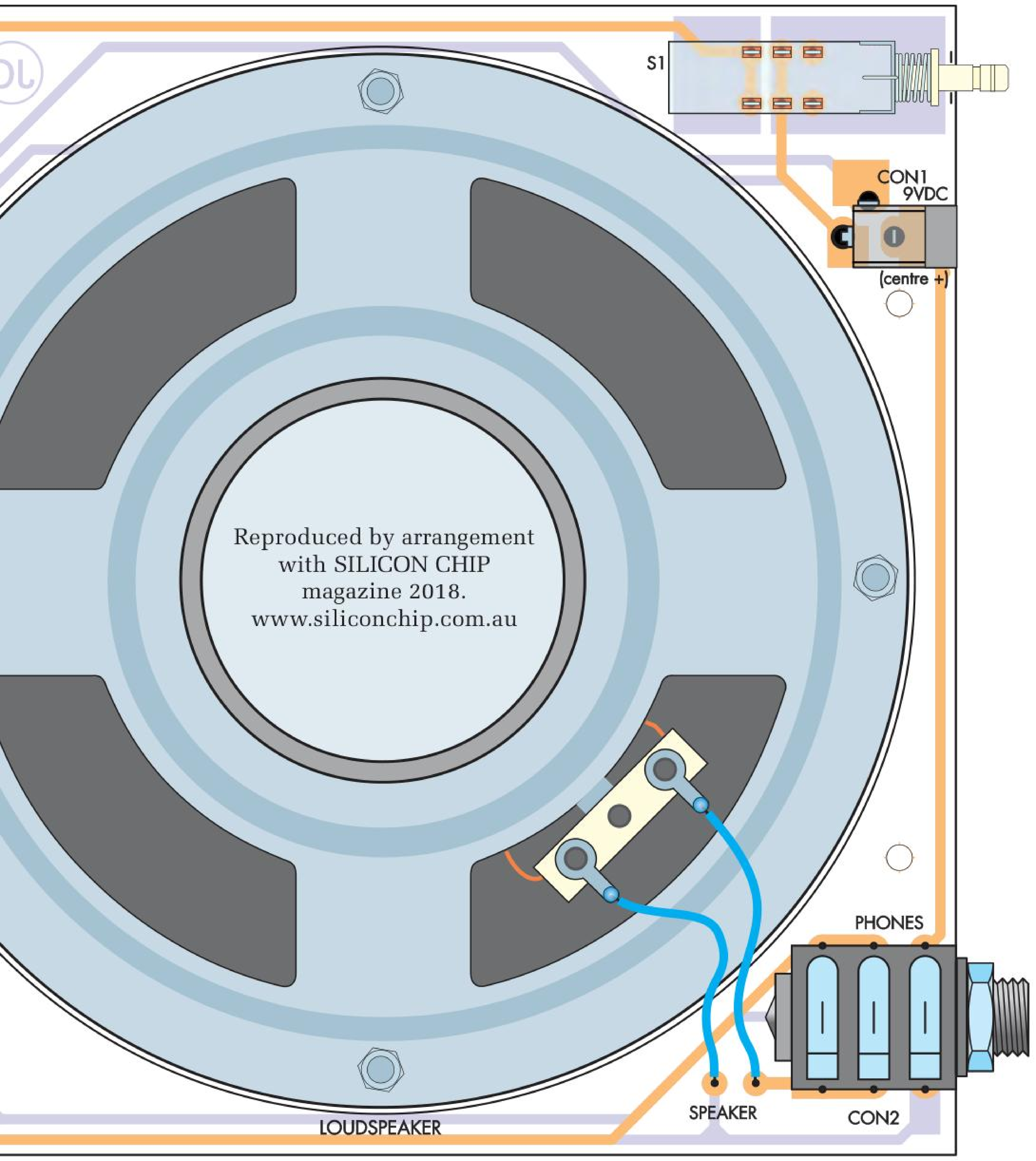
The major difference between this project and any other that you may build is the need for alignment. Even if you have assembled the radio precisely as we have described so far, there is little chance that it will work satisfactorily when you first turn it on.

This is because even tiny variations in component values and characteristics and even slightly different PCB track widths and fibreglass thickness can cause frequency shifts which throw the workings of the radio off.

There are various adjustments to compensate for this, including the adjustment slugs in the IF transformers, which need to be 'tweaked' to give the best gain and frequency response.

You will also need to adjust the slug in the oscillator coil and the trimmer capacitors associated with the tuning gang to give the best tracking. The resonant circuit of the oscillator (T2, VC3 and VC4) must track with the aerial resonant circuit (T1, VC1 and VC2) across the whole of the broadcast band.

Otherwise, the set's sensitivity will vary quite markedly as you tune it.



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This also helps to ensure that stations appear at their correct locations on the tuning dial.

Before you start the alignment process, rotate trimpot VR2 fully anticlockwise. This will reduce the quiescent current in the output stage transistors, Q6 and Q7, to zero. Rotate the volume control pot and the tuning knob fully anticlockwise too.

This done, connect a 9V battery or 9V DC power source (a 9V DC plugpack or 9V power supply – but make sure the centre pin is positive) and then measure voltages around the circuit. Connect the negative probe of your multimeter to the GND test point and then verify that the following voltages are correct:

TP+ (8.88V) TP1(1.55V) TP2(8.88V)
TP3 (1.1V) TP4 (8.88V) TP5(1.78V)
TP6 (9V) TP7 (4.7V) TP8 (4.3V)
TP9 (3.73V) TP10 (4.2V).

In each case, the voltage should be within about 10% of the value noted above assuming that the supply is exactly 9V. If the voltages are quite different from the values listed above, then you should investigate why. For example, if your supply is actually putting out 9.5V then the readings which are supposed to be 8.88V could easily be 9.38V instead (and TP6 will be 9.5V).

By the way, these voltages are 'no signal' voltages. That means little or no signal should be picked up by the input stage and the volume control is turned down so that there is no signal going through the amplifier stages. The presence of signals will alter these voltages, although not greatly.

You can also measure the current drain now. This can be done by connecting your multimeter (selected for measuring a low current range) across the on/off switch between the centre and rear terminals at one side of the switch. Alternatively, connect the multimeter between the anode of diode D3 and the 9V battery positive terminal.

With the switch set switched off, the current through the meter should be less than 10mA. We measured 3mA on our prototype. If you measure a lot more (more than 10mA) or a lot less (under 1mA), disconnect the multimeter and check the board carefully for assembly errors and solder bridges.

Aligning the IF stages involves injecting a 455kHz signal into the front end of the circuit. As mentioned, earlier, the *DDS IF Alignment* unit from September 2018 makes this easy. See the side panel on how to do this.

The alternative is to connect an RF oscillator, set to 455kHz, through a 1nF ceramic capacitor to test point TP1. If you don't have an RF oscillator, you could use an audio signal generator set to produce a square wave at 152kHz with an 800mV output level. Since a square wave produces odd order harmonics, it is the third harmonic (3 x 152kHz) from the square wave at 456kHz that will be your signal for the IF alignment.

Connect your multimeter (set to read DC volts) between test point TP3 and ground. Set the RF generator to give a signal output of about 1mV RMS or the audio signal generator square wave to 800mV RMS. The idea is to now adjust each of the slugs in the IF transformers in turn for a minimum voltage on test point TP3.

As you adjust the slugs, the gain of the IF stages improves and the signal fed to the detector diode (D1) increases. The detector diode rectifies the IF signal and so, as the signal increases, the negative voltage produced by the detector increases. Hence, the voltage at test point TP3 decreases.

Note that after adjusting all the slugs, you may wish to go back through them again and check that they are all set at their optimum position. It's sometimes possible to make improvements the second time around that were hard to see initially.

Oscilloscope method

If you have access to an oscilloscope, you can connect it to TP6 and observe the IF signal directly.

Now, as you adjust the slugs, you will see the signal increase or decrease. Adjust the slugs for the best possible (ie, highest) signal amplitude.

If you notice any clipping of the signal at TP6, just reduce the signal input from your RF oscillator.

Tracking adjustments

These adjustments ensure that the RF input circuit and the local oscillator cover the correct range of frequencies so that you can tune over the entire broadcast band. Ideally, you need an RF signal generator to do this task. If you don't have access to one, you will have to rely on tuning stations at the top and bottom of the band.

In Europe, the broadcast band is specified as 526.5 to 1606.5kHz, so to be sure you are covering this band, it is normal to make a radio tune over a slightly wide range, eg, 525-1620kHz.

Let's first proceed on the basis that you have an RF signal generator. If you

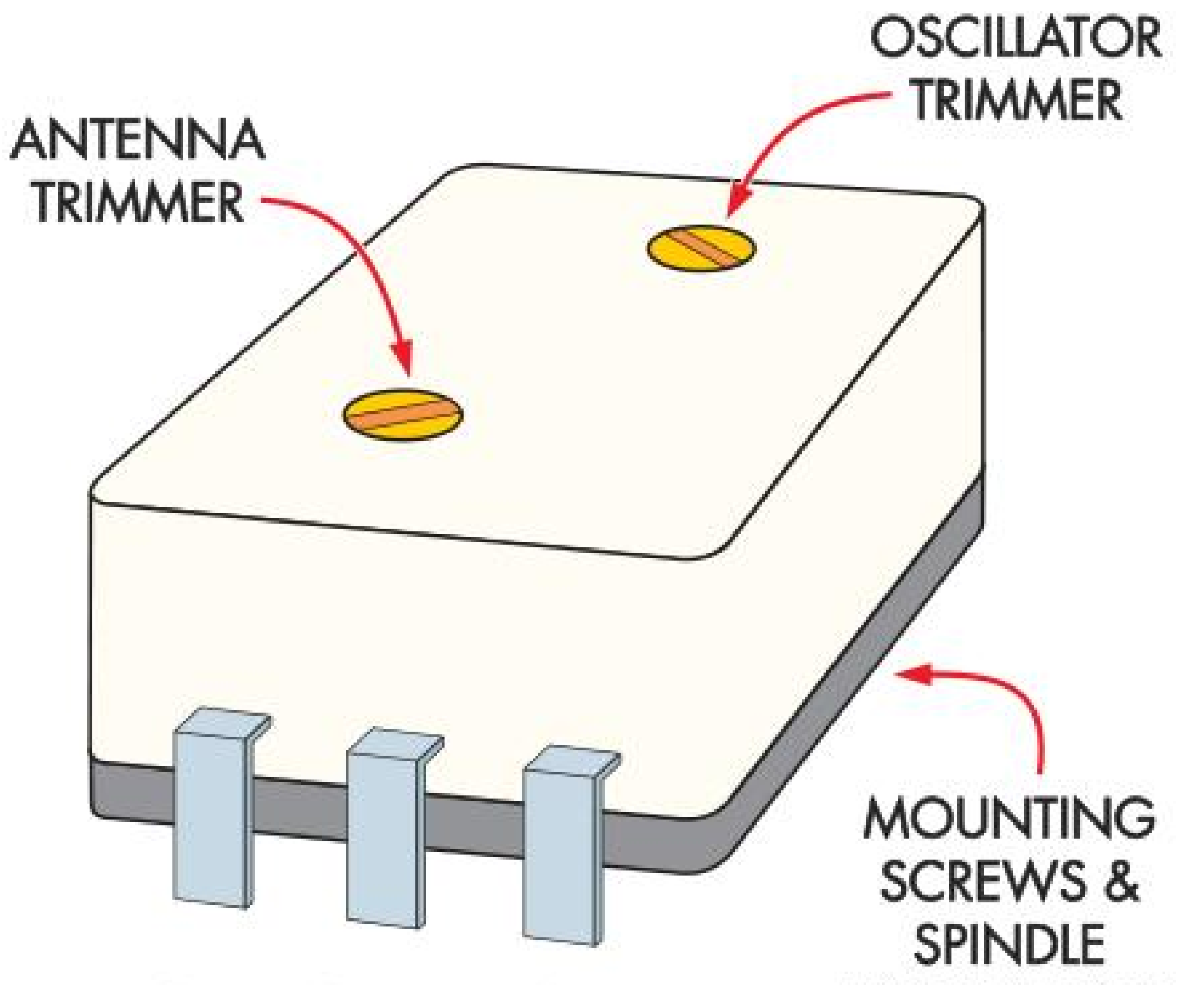

OSCILLATOR
TRIMMER
ANTENNA
TRIMMER
MOUNTING
SCREWS &
SPINDLE
UNDERNEATH

Fig.3: this shows the locations of the antenna and oscillator trimmer adjustments on the tuning gang.

don't have an RF signal generator, see the section entitled 'Setting the tuning range without an RF generator'.

With signal applied to TP1 via a 1nF capacitor, set the generator to 525kHz and rotate the tuning knob fully anticlockwise. This sets the plates of the tuning gang 'in mesh', which is the maximum capacitance condition, for the low-frequency end of the band. Now adjust the slug in the oscillator coil for maximum loudness of the signal via the speaker, or (if you are using an oscilloscope) for maximum signal amplitude at TP6.

Next, rotate the tuning knob so that it is fully clockwise. Set your RF signal generator to 1620kHz. Tune the adjustment screw on the back of the tuning gang labelled 'oscillator trimmer' (see Fig.3) for maximum signal amplitude, as before. Rotate the tuning knob fully anticlockwise and redo the oscillator coil slug adjustment again at 525kHz.

This done, go back to the top of the band at 1620kHz and adjust the oscillator trimmer again. The adjustments need to be done a number of times as the top adjustment affects the bottom adjustment and vice versa.

You have now adjusted the oscillator range so that the broadcast band can be tuned in and this also ensures that the stations are tuned in at the locations indicated on the dial.

As a point of interest, the oscillator will now be tuned over the range 980-2075kHz. That's 525kHz plus the IF of 455kHz to 1620kHz, also plus 455kHz.

Now you need to adjust the ferrite rod coil and antenna trimmer (on the back of the tuning gang) to maximise sensitivity by ensuring the aerial circuit is resonant at the tuned frequency. Set the tuning knob fully anticlockwise and set the RF signal generator to 525kHz, then move the coil along on the ferrite rod until the signal amplitude is at a peak.

You may have to (carefully!) heat up the coil with a hot air gun to melt the wax between the coil and ferrite rod, before the coil can be moved.

Now set the RF generator frequency to 1620kHz and turn the adjustment screw on the back of the tuning gang labelled 'antenna trimmer' (as shown in Fig.3) until you peak the incoming signal again.

You should now repeat these adjustments for the optimum response. When this is done, the ferrite rod coil should be fixed in place by re-melting the wax and allowing it to set. That completes the alignment of the radio.

Quiescent current

All that remains to be done is to set the quiescent current in the audio power amplifier by means of trimpot VR2. The best way to adjust the quiescent current is to feed a sinewave-modulated signal into the front end of the radio from an RF signal generator.

Connect an oscilloscope to the output at test point TP10 and adjust the volume control for a signal amplitude across the speaker of about 2-3V peak-to-peak. At this stage, VR2 should still be fully anticlockwise. If you now have a look at the signal on the scope screen, you will see the classic sinewave with crossover distortion notches in the waveform at the crossover point (see Scope3).

Now rotate VR2 slowly clockwise and you should see the crossover nicks disappear from the waveform and, at the same time, the sound should become cleaner.

Rotating VR2 to reduce the crossover distortion will not increase the current drain by much (typically no more than a milliamp) but it will make a big difference to the sound quality.

No 'scope?

If you don't have an oscilloscope, you can apply a signal at 1kHz from an audio generator (100mV is suitable) to the centre of VR1, with VR1 set to mid-position. This will apply audio directly to the amplifier.

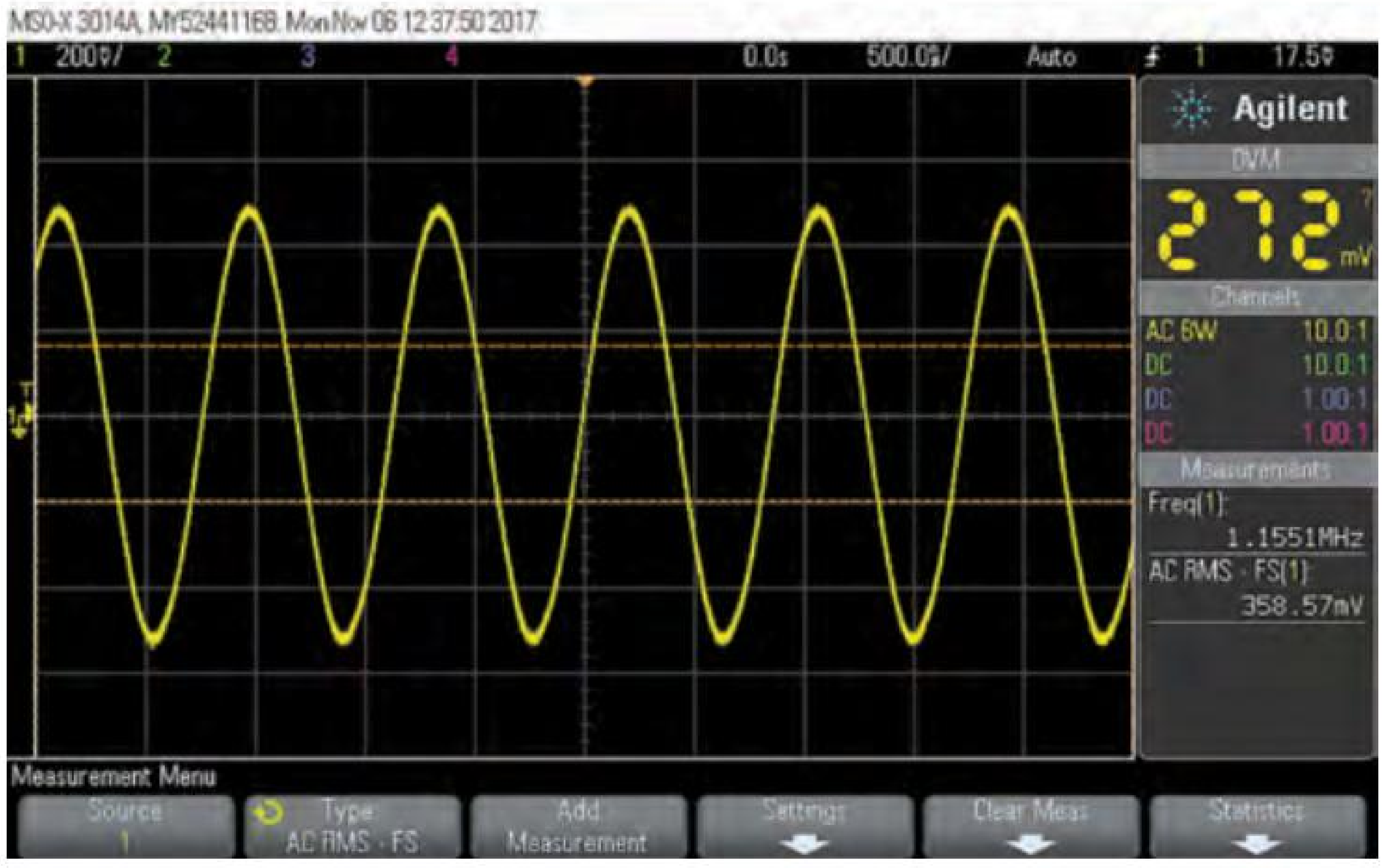
Adjust VR2 for minimum distortion either by listening to the sound (it should become 'pure' with adjustment).

By the way, you should measure the current drain of the radio while you are adjusting the quiescent current with trimpot VR2.

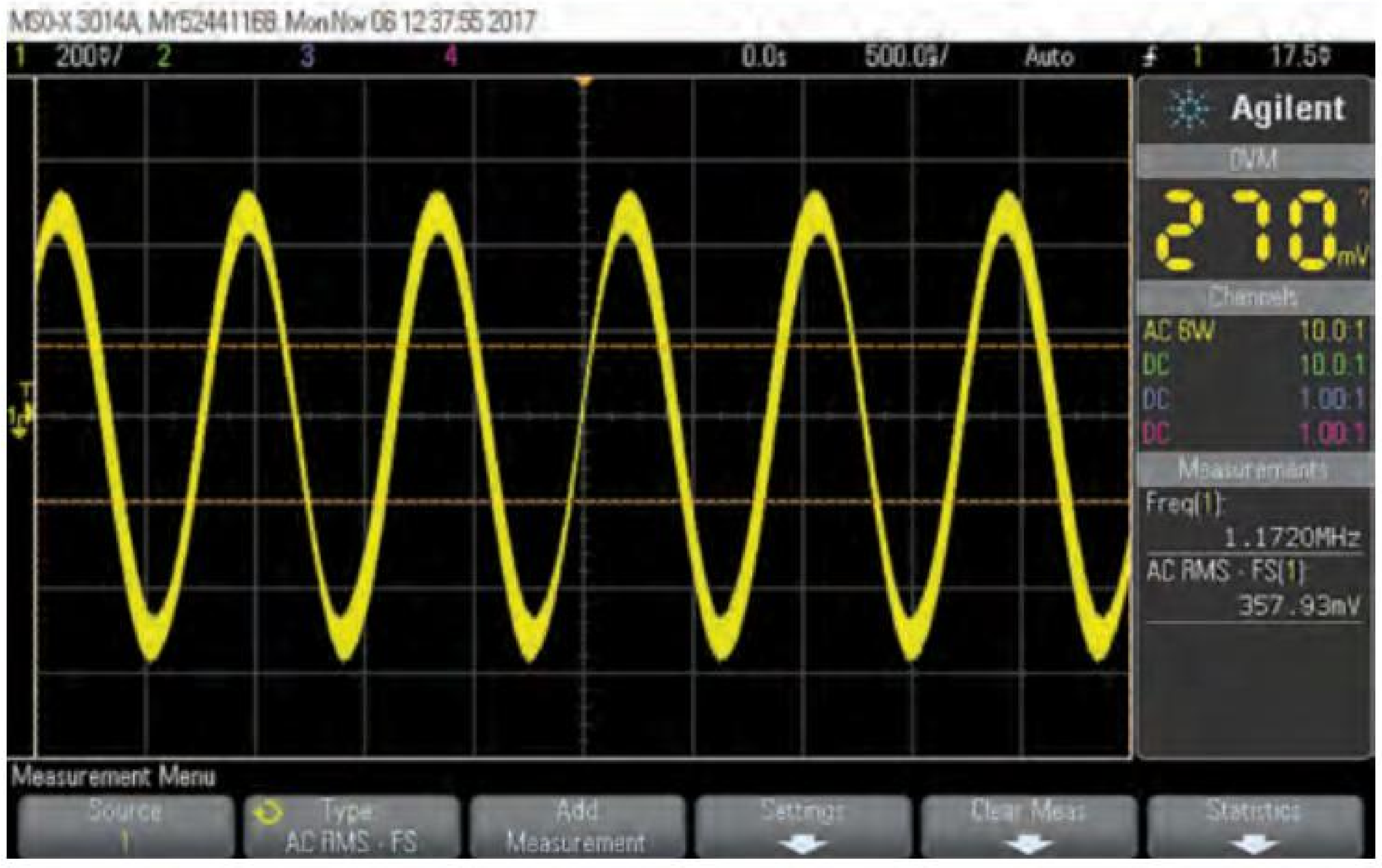
Typically, the current drain of the radio at 9V should be less than 10mA when the volume control is at minimum setting (ie, no signal through the audio amplifier stages).

With the volume control well advanced, to make the radio quite loud, the current drain may be 40mA or more. Don't rotate VR2 any more than necessary as this will increase dissipation in the output transistors and will flatten the battery faster when listening.

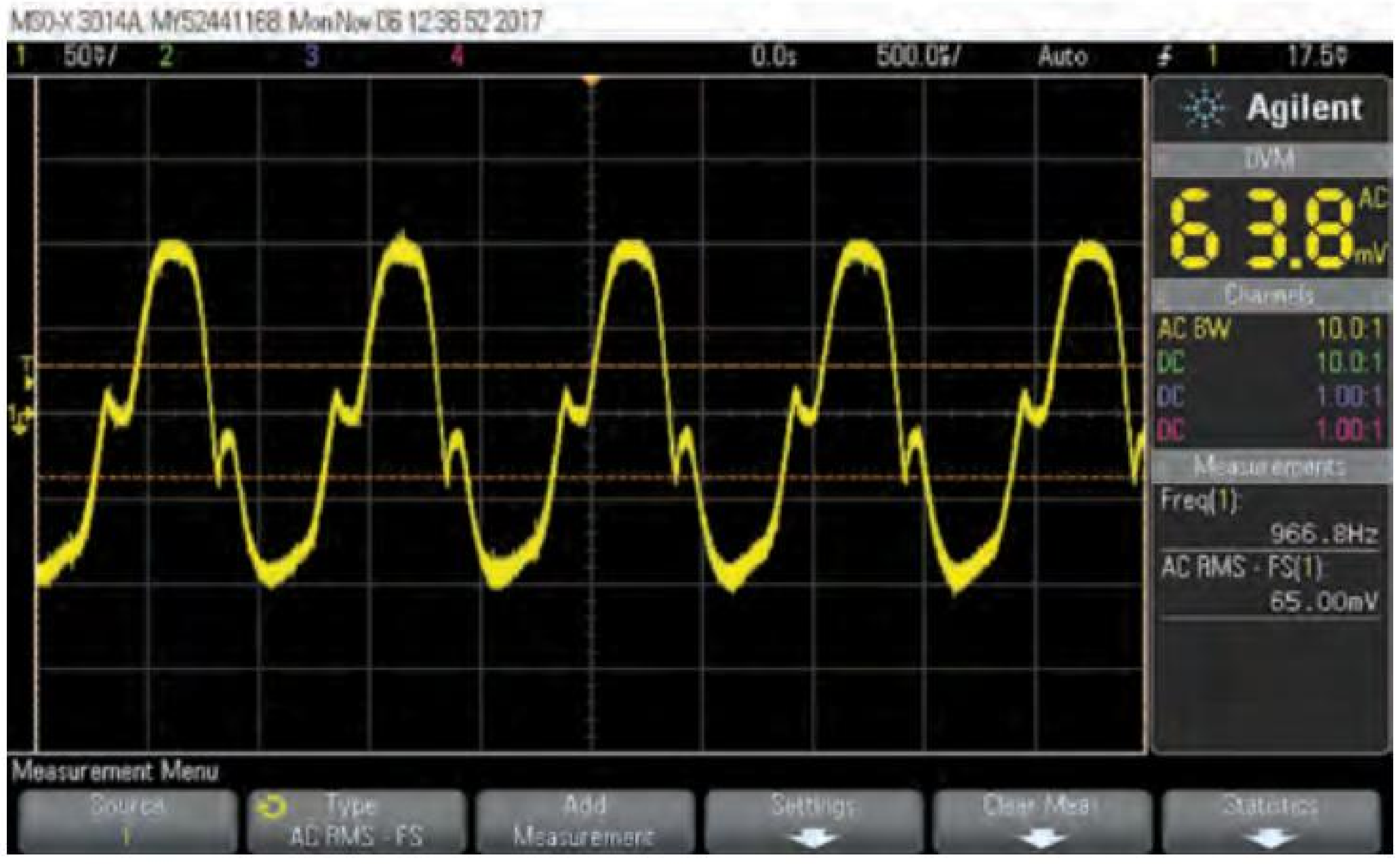
If in doubt, back it off a bit (rotate it anti-clockwise) until you hear an increase in distortion, then rotate it a tiny bit clockwise until that distortion is gone and you are near the ideal setting. Note that using the radio with high volume will flatten the battery much more quickly than at low volume.


MSO-X 3014A, MY52441168: Mon Nov 06 12:37:50 2017
1 200mV/ 2 3 4
0.0s 500.0ns/ Auto
1 17.5mV
Agilent
DVM
272 mV
Channels
AC BW 10.0:1
DC 10.0:1
DC 1.00:1
DC 1.00:1
Measurements
Freq(1): 1.1551MHz
AC RMS - FS(1): 358.57mV
Measurement Menu
Source 1
Type AC RMS - FS
Add Measurement
Settings
Clear Meas
Statistics

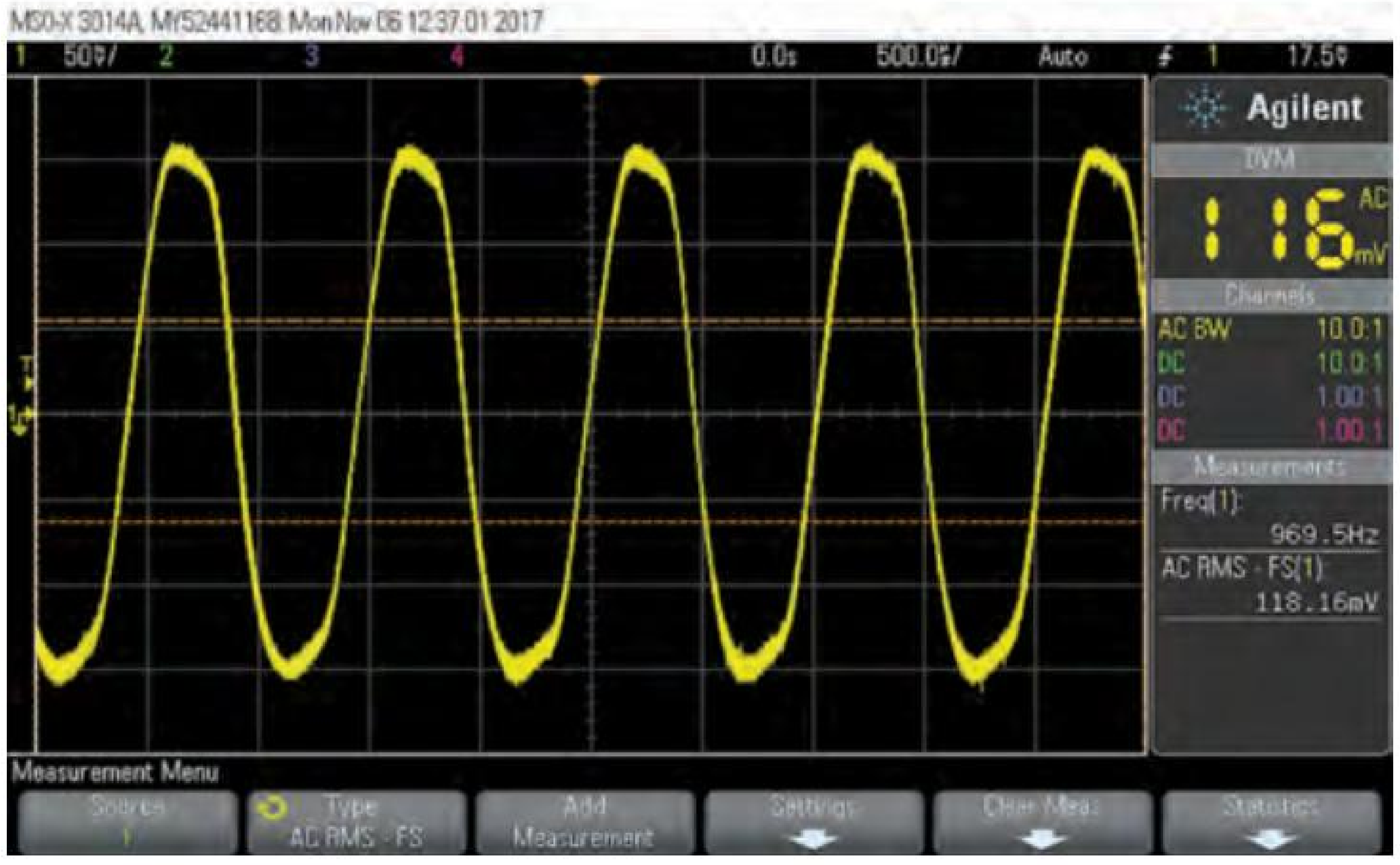
Scope1: voltage at the collector of Q1 with the set tuned to around 700kHz; 700kHz + 455kHz = 1.155MHz). You can see that the oscillator waveform is a clean sinewave with an amplitude of around 350mV RMS.


MSO-X 3014A, MY52441168: Mon Nov 06 12:37:55 2017
1 200mV/ 2 3 4
0.0s 500.0ns/ Auto
1 17.5mV
Agilent
DVM
270 mV
Channels
AC BW 10.0:1
DC 10.0:1
DC 1.00:1
DC 1.00:1
Measurements
Freq(1): 1.1720MHz
AC RMS - FS(1): 357.93mV
Measurement Menu
Source 1
Type AC RMS - FS
Add Measurement
Settings
Clear Meas
Statistics

Scope2: now a test signal has been coupled into the ferrite rod. The test signal was modulated onto a 720kHz carrier. You can see the effect of signal modulation in the thickening of the trace away from the centre.


MSO-X 3014A, MY52441168: Mon Nov 06 12:36:52 2017
1
50mV/
2
3
4
0.0s
500.0µs/
Auto
1
17.5mV
Agilent
DVM
63.8 AC mV
Channels
AC BW 10.0:1
DC 10.0:1
DC 1.00:1
DC 1.00:1
Measurements
Freq(1):
966.8Hz
AC RMS - FS(1):
65.00mV
Measurement Menu
Source 1
Type AC RMS - FS
Add Measurement
Settings
Clear Meas
Statistics

Scope3: waveform across the speaker with VR1 at its minimum setting and a ~1kHz modulated RF test signal inductively coupled into the antenna. The zero crossing artefacts are quite severe with no quiescent current.


MSO-X 3014A, MY52441168: Mon Nov 06 12:37:01 2017
1
50mV/
2
3
4
0.0s
500.0µs/
Auto
1
17.5mV
Agilent
DVM
116 AC mV
Channels
AC BW 10.0:1
DC 10.0:1
DC 1.00:1
DC 1.00:1
Measurements
Freq(1):
969.5Hz
AC RMS - FS(1):
118.16mV
Measurement Menu
Source 1
Type AC RMS - FS
Add Measurement
Settings
Clear Meas
Statistics

Scope4: the audio output sounded very raspy when capturing Scope3. We then rotated VR1 clockwise until the sound became much cleaner and took the screen grab shown here. The signal looks much more like a sinewave.

The acrylic case

Because it is self-contained (ie, fully on one PCB) the *Super-7 AM Radio* would be quite happy working without a case. But if you want a really professional finish, you'll want to put it into the purpose-designed acrylic case. Its appearance is not unlike the mantel radios of yesterday, only it is shiny black!

The case measures 327 × 155 × 58mm (w × h × d) and the front, sides, top and bottom are a smart high-gloss black. The back panel is transparent so everyone can admire your handywork!

Provision is made in the left end panel for the on-off switch, a DC power plug and the 6.5mm headphone socket.

On the front panel, attractive slots are milled for sound output immediately in front of the speaker and at the right end there's a matching 105mm hole for the clear acrylic tuning 'dial', which reveals the screen-printed PCB underneath with major radio stations.

While you can easily move the tuning dial with your fingers, we gilded the lily somewhat by gluing a large knob to the centre of the dial (a knob makes it easier to find elusive stations!) – whether or not you add a knob is entirely up to you. Immediately underneath and to the left of the tuning dial is the single 'volume' control

The case simply slots together and everything is held in place by four 50mm long pillars which go from front to back – more on these shortly.

We've also made provision on the bottom front of the case for a pair of rubber feet which can angle the whole receiver back slightly. Again, this is entirely optional.

Putting the case together

Remove the nuts from the volume control pot and headphone socket, if fitted. It doesn't matter if the clear acrylic 'dial' is fitted to the tuning capacitor; it can be done now or later.

Start with the front panel. Insert four M3 × 15mm screws through the four holes near the edges and put a washer and nut on each to hold them in place. Now slide the receiver PCB down over these screws, obviously oriented so the speaker sits behind the slots and the dial markings behind the 105mm hole.

Slide the left end panel into its slots on the front panel, at the same time engaging the on/off switch shaft and the 6.5mm headphone socket. You will probably have to lift the PCB on this end to allow this.

When in position, refit the nut onto the headphone socket – this will hold the end panel in place.

Now you can slide the bottom, top and right end panels into place, with their tabs fitted into the slots on the front panel and each other.

Threaded standoffs

It's not easy (impossible?) to buy a threaded standoff long enough (45mm+) to hold the rear panel onto the front panel. If you can find (or make!) a 45mm M3-threaded standoff, more power to you!

We made ours with a combination of 15mm and 25mm M3-threaded standoffs, M3 studs to join them into single 40mm lengths, plus a few M3 nuts and washers to end up with the 50mm length required.

Setting the tuning range without an RF generator

In the accompanying procedure for setting oscillator and antenna tracking, we assumed that you had access to an RF signal generator. For many constructors, this won't be the case and they will have to rely on broadcast signals at the top and bottom of the broadcast band.

Chicken and egg

However, this poses something of a 'chicken and egg' situation. How do you do the tracking adjustments if you cannot receive the signals? In most cases, you should be able to receive signals at or near the bottom of the broadcast band especially at night (typically high-power radio stations).

Top-end signals

However, picking up a signal at the top end of the band might not be anywhere as easy. However, there is a solution if you have another AM Radio since every superhet has a local oscillator and for an AM broadcast receiver, this oscillator will usually be 455kHz above the tuned frequency. Therefore, you can use the local oscillator in your other AM radio to set the tracking adjustments at the top of the band.

Second radio method

The method to follow is this: place the ferrite rod of the Super-7 AM Radio near the antenna rod of the other AM radio. This rod will usually be at the top of the case. Rotate the tuning dial of the Super-7 AM Radio fully clockwise to tune to the top of the band. Tune your other AM radio to 1165kHz or as close to this as you can. This will set its local oscillator to 1620kHz. That's the top of the band on the Super-7 AM Radio's dial.

As you do so, you should be able to hear faint heterodyne whistles from the speaker of the AM radio. Now proceed to peak the antenna and oscillator circuits as described in the article.

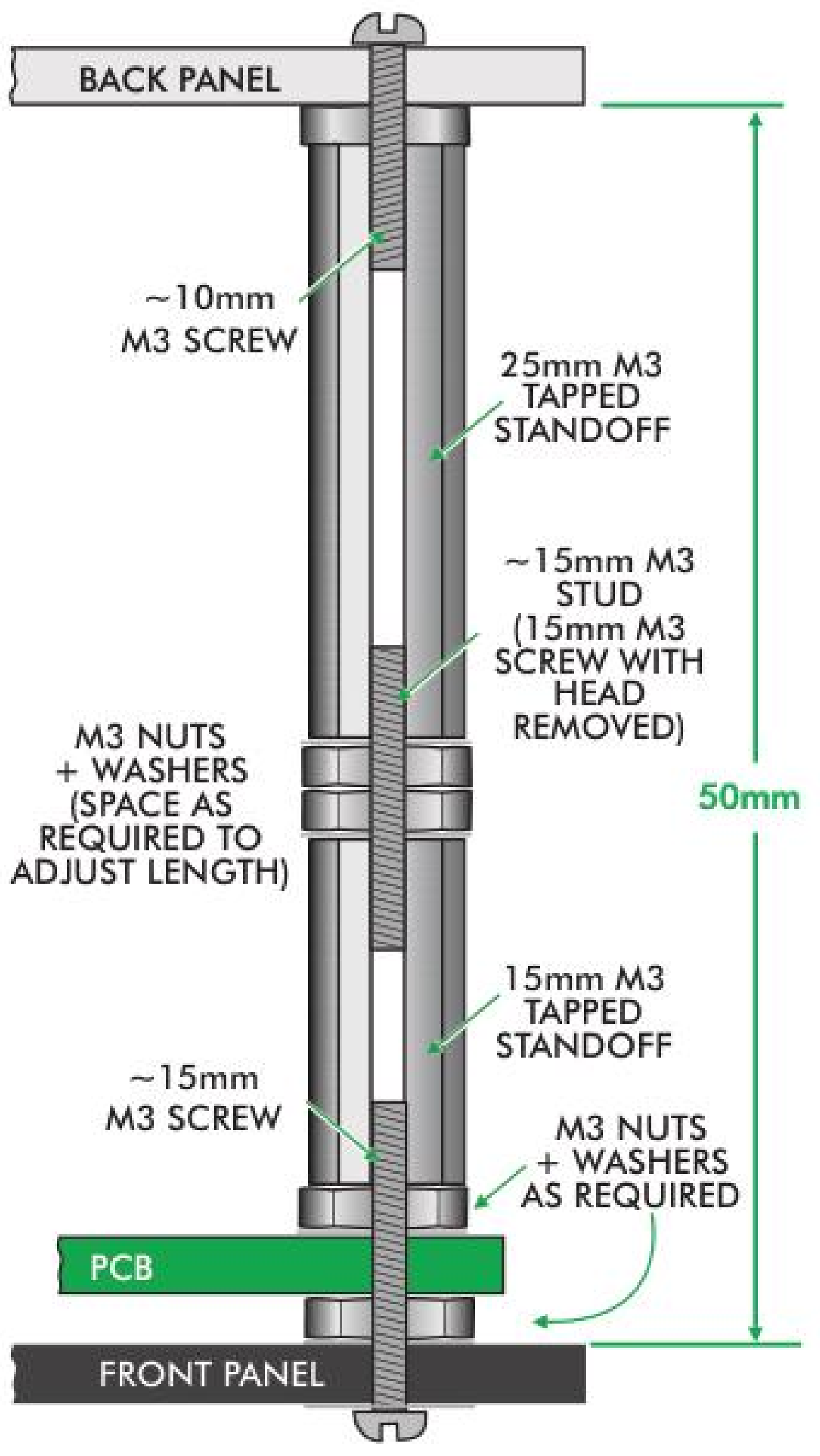

BACK PANEL
~10mm M3 SCREW
25mm M3 TAPPED STANDOFF
~15mm M3 STUD (15mm M3 SCREW WITH HEAD REMOVED)
M3 NUTS + WASHERS (SPACE AS REQUIRED TO ADJUST LENGTH)
50mm
15mm M3 TAPPED STANDOFF
~15mm M3 SCREW
M3 NUTS + WASHERS AS REQUIRED
PCB
FRONT PANEL

Fig.4: you need four 50mm M3 threaded standoffs – but just try to buy them! We made ours from 15mm and 25mm standoffs, joined with an M3 stud made from a headless 15mm M3 screw. Nuts and washers were used to pack it out to 50mm long.

The 'stud' which joins the 15mm and 25mm lengths was simply a short (15mm) M3 screw with its head cut off with a hacksaw. (You will probably need to run a nut over the cut-off section to reform the thread).

Two M3 nuts were used between the two standoffs as spacers. Fig.4 shows this a little more clearly. The overall length of the standoff, top of PCB to bottom of rear panel, is 50mm. Given that nuts vary all over the place in height, simply choose the number of nuts and/or washers to make your standoffs 50mm long.

We made four of these. The bottom ends screw onto the M3 screws which pass through the case front panel (with a nut) and then the PCB. The top ends fasten to the four M3 screws which hold the rear panel in place.

Frequency (Hz)
0455000
IF Align
Level
AM (1 kHz)
100

Using the DDS Superhet Alignment Unit (Sept 18)

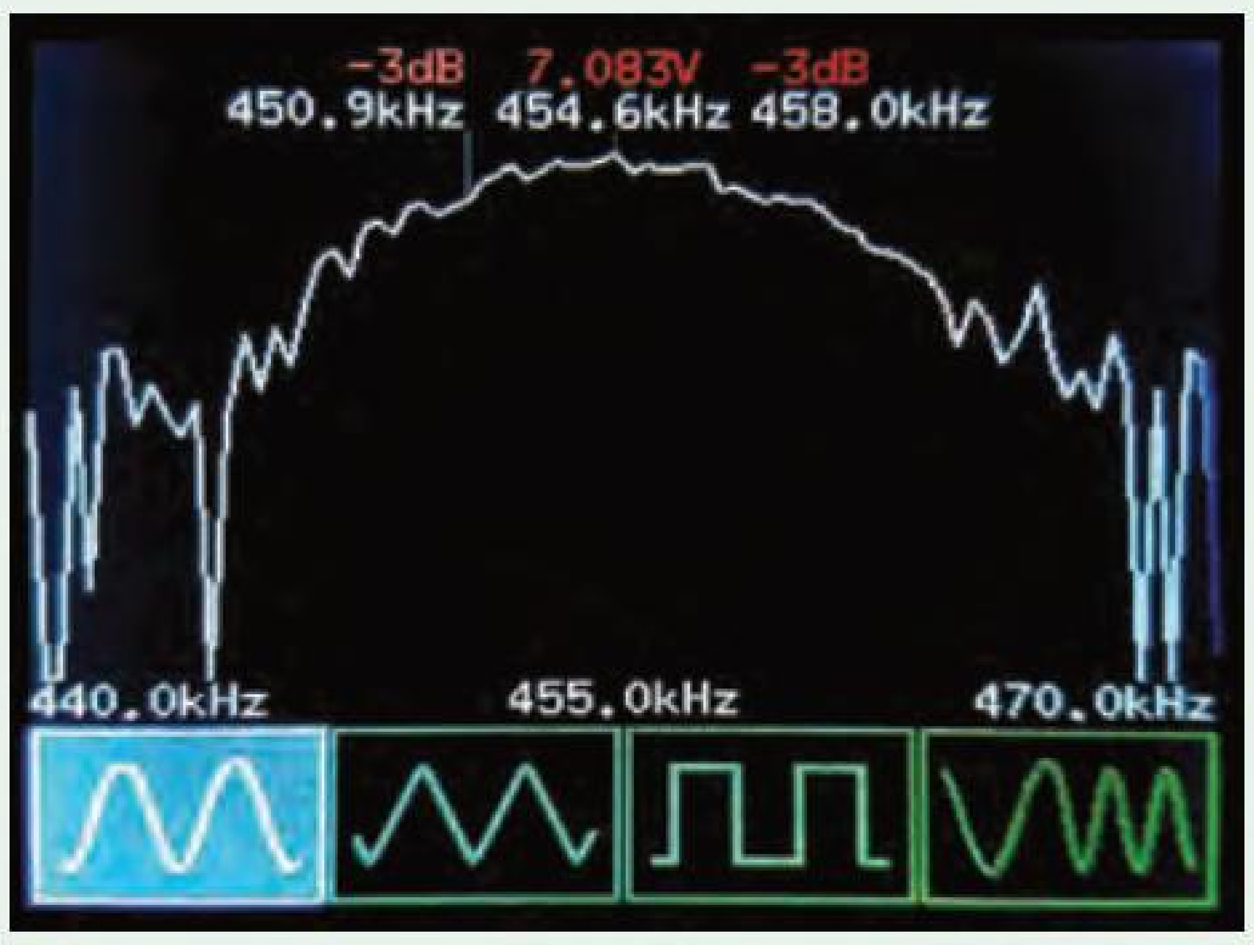
The DDS IF Alignment unit makes aligning the Super-7 quite straightforward. While its IF alignment mode is handy for verifying the alignment is correct, the AM modulated signal generator is actually the mode we used the most during alignment.

The DDS module allows you to generate the 455kHz, 525kHz and 1620kHz test signals with or without modulation. Simply enter the required frequency and select sinewave mode.

We produced a maximum (or near maximum) amplitude signal and fed it to a small wire loop which we placed near the ferrite rod. However, you could also use the onboard attenuator to produce a lower-level signal suitable for direct injection via a 1nF capacitor, as per the main text.

Note that we found proper alignment much easier with the aid of a scope since this allows you to see how cleanly the modulated test signal is being demodulated and you can tweak the alignment to give not only the strongest but also the least distorted signal output.

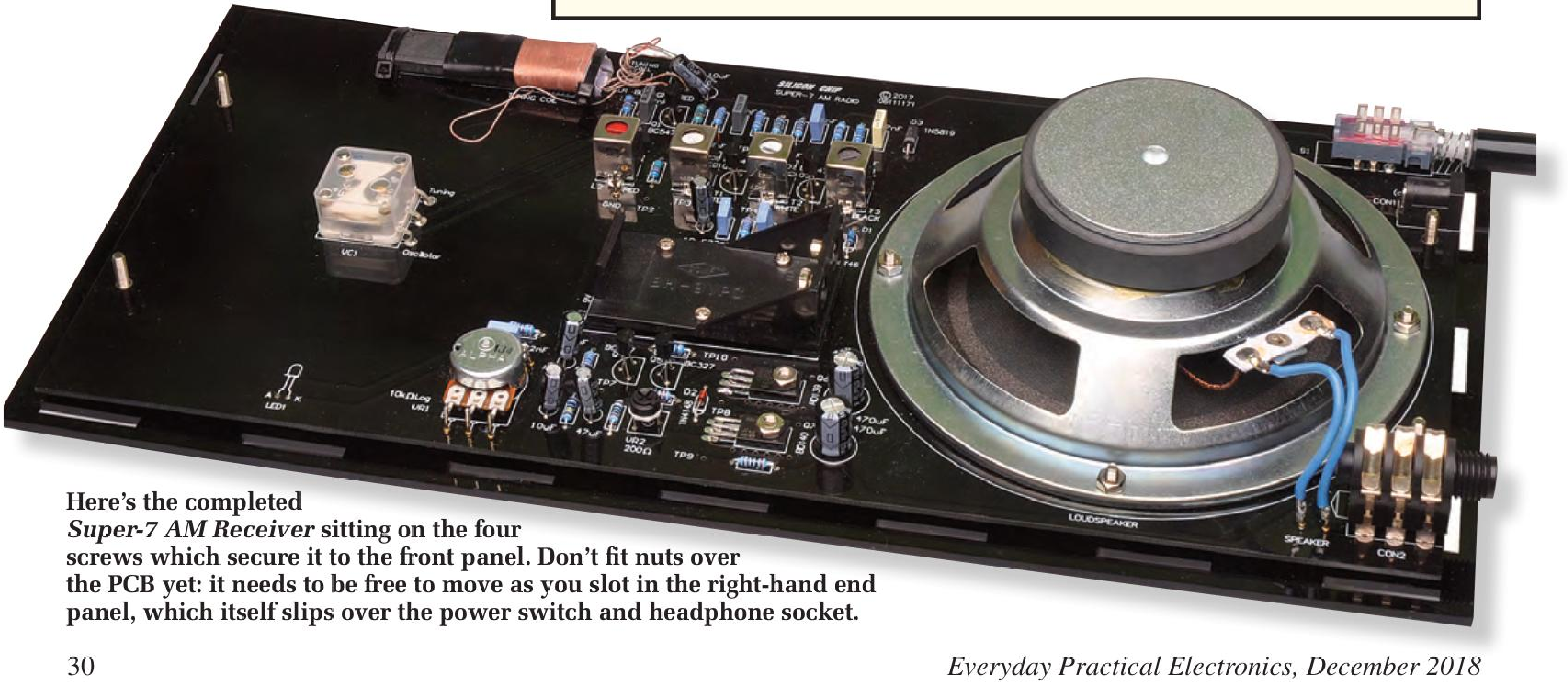
Once you've completed the alignment procedure as stated in the main text, you can then set the generator frequency and switch to IF alignment mode to verify that the IF bandwidth peaks around 455kHz and has the correct ~10kHz bandwidth to the –3dB points, as shown below.


-3dB 7.083V -3dB
450.9kHz 454.6kHz 458.0kHz
440.0kHz
455.0kHz
470.0kHz

Hard-to-find parts – Super-7 AM Radio Receiver

Apologies – last month, we mistakenly separated these components from their sources. This list should fill in any purchasing blanks.

1 set of laser-cut acrylic case and dial pieces (SILICON CHIP Online Shop Cat SC4464)
1 AM radio coil pack (Jaycar LF-1050) (T2-T5) (Two packs needed for two white coils – if you wish, one pack will suffice and either of the white coils could be replaced with a yellow coil, but performance may well be reduced.)
1 mini tuning gang capacitor (Jaycar RV-5728) (VC1-VC4)
1 ferrite rod with coil (Jaycar LF-1020) (T1)
1 100mm (4-inch) 4- or 8-ohm loudspeaker (Jaycar AS3008)
1 DPDT push-on/push-off switch (Altronics S 1510) (S1)
1 round knob for switch S1 (Altronics H 6651)
1 16mm 10kΩ logarithmic taper potentiometer with 6.35mm D-shaft (Jaycar RP7610, Altronics R2253) (VR1)
1 2.1 or 2.5mm inner diameter DC socket (Altronics P 0621A, P 0620, Jaycar PS-0519, PS-0520) (CON1)
1 6.35mm stereo switched jack socket (Altronics P 0073, Jaycar PS-0190) (CON2)
1 9V PCB battery holder (Altronics S 5048, Jaycar PH-9235)
Optional knob to suit the dial (Jaycar HK7010/HK7011)


SILICON CHIP
SUPER-7 AM RADIO
LOUDSPEAKER
SPEAKER
CON2

Here's the completed *Super-7 AM Receiver* sitting on the four screws which secure it to the front panel. Don't fit nuts over the PCB yet: it needs to be free to move as you slot in the right-hand end panel, which itself slips over the power switch and headphone socket.

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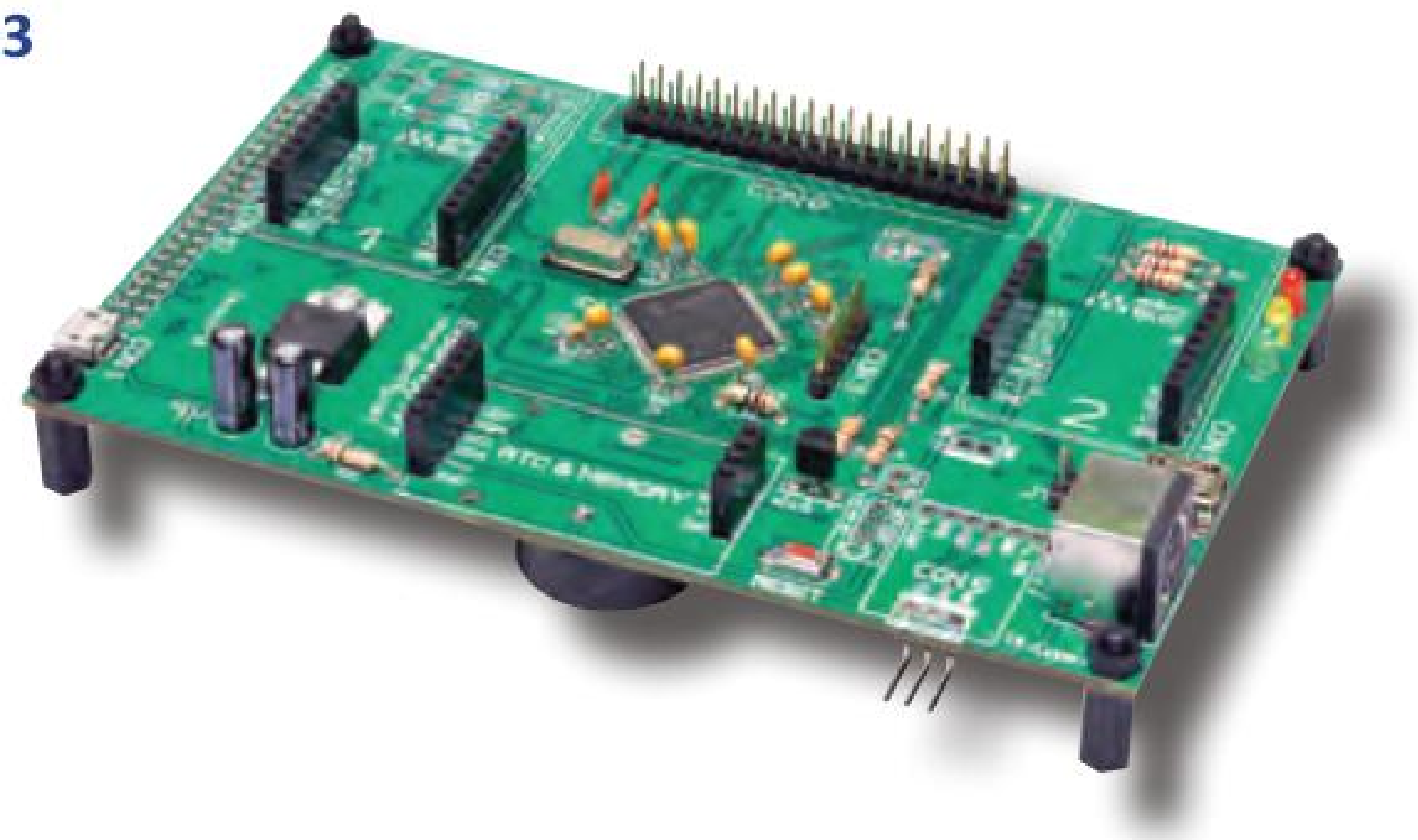
COMPETITION

This month, ***EPE*** and **micromite.org** are giving you a chance to win a fully assembled Micromite Plus Explore 100 module (TFT screen not included). For details about this powerful, yet compact module, turn to page 28 in the September 2017 edition of ***EPE***.

To enter, simply send an email to **epe@micromite.org** with the email subject as: **6GHz3**



Please ensure you email before the closing date: 30 November 2018

The name of the lucky winner will be published in a future edition of ***EPE***.

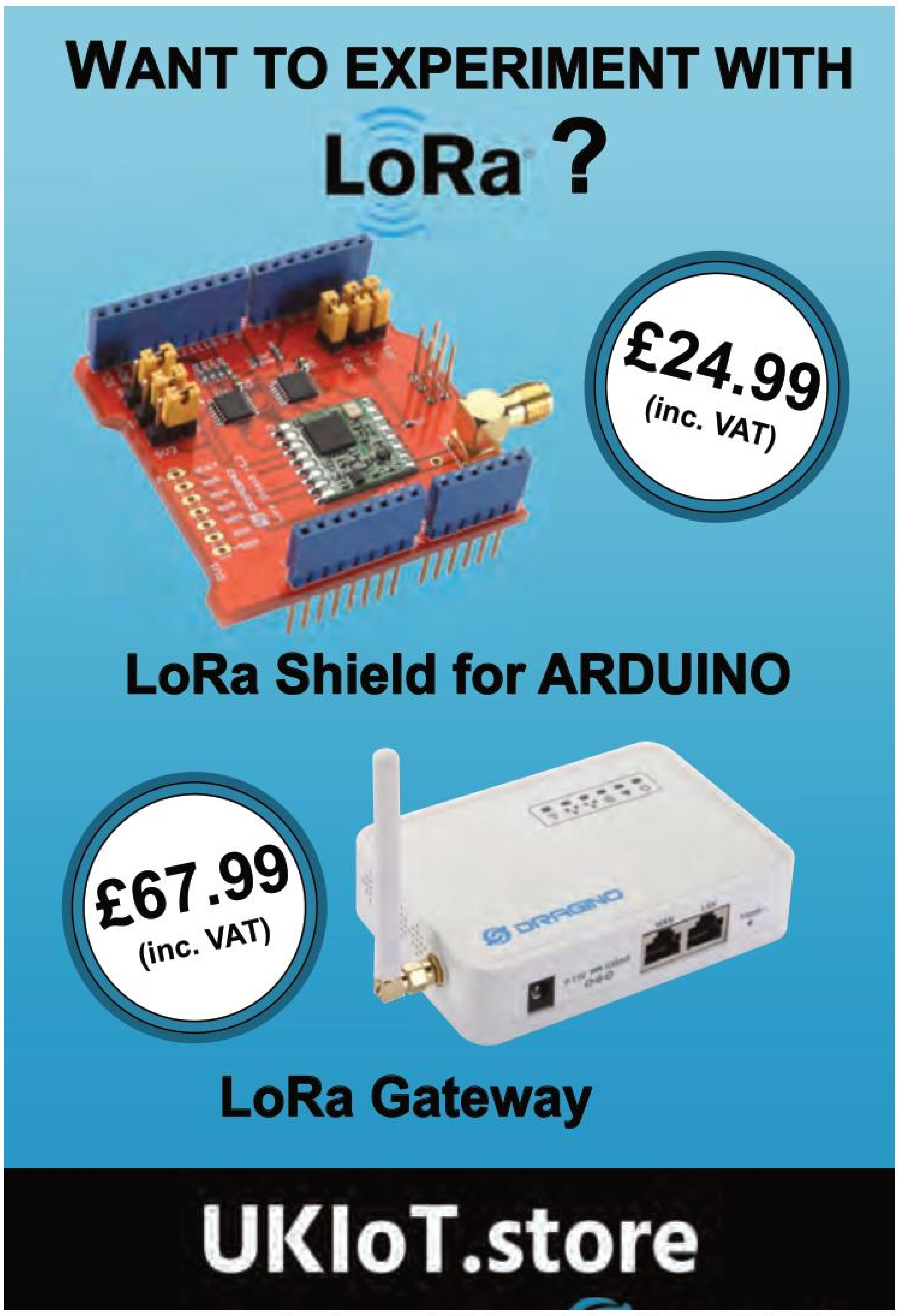
Look out for future competitions to win other fantastic Micromite products.

Good Luck!

WIN A Micromite Plus Explore 100!

T&Cs

1. You may enter as many times as you wish
2. All entries must be received by the closing date
3. Winners will be notified by email within one week after the closing date
4. Winners will need to confirm a valid shipping address to which their prize will be shipped
5. UK winners will have their prize sent via Royal Mail's Special Delivery service
6. Overseas winners will have their prize sent by Royal Mail's International Tracked & Insured service



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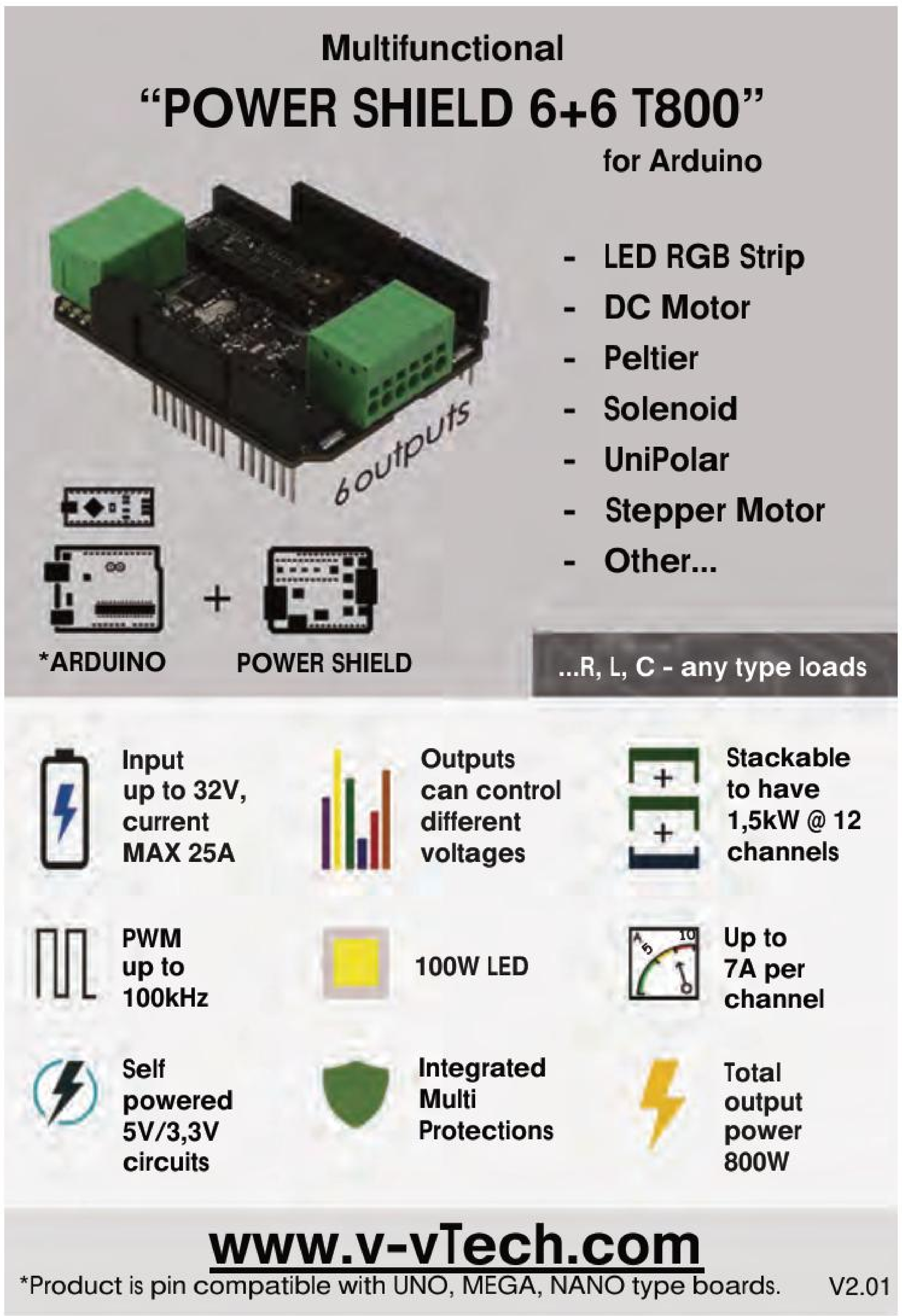

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Integrated Multi Protections

Total output power 800W

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*Product is pin compatible with UNO, MEGA, NANO type boards. V2.01

TCXO: 16.368MHz
CPU : 100.623MHz
5 sats, 01:22:17am 04/09/2017
33°45'37"S 151°16'49"E 42m
GPS lock for: 11m52s
5.43526185GH
Precision: ±200Hz (82ppb)
Accuracy : ±720Hz (29
Mode : frequency, averaging (3
Input: SMB (20MHz-6GHz+) 50 oh

6GHz+ Touchscreen Frequency and Period Counter

Part 3: by Nicholas Vinen

Having described our new *6GHz+ Touchscreen Frequency/Period Counter* in the first article (October) and then built and tested it (November), we shall now show how to use it and explain what it can do. Apart from its very wide frequency range, it offers outstanding accuracy.

In Parts 1 and 2 we explained how to build the *Frequency Meter; now* it's time to program the Explore 100 with the software.

We don't supply the PIC32 pre-programmed with the BASIC code because the Explore 100 provides a USB interface that makes loading it quite easy.

The PIC32 that is supplied in the Explore 100 kit (from **micromite.org**) already has the MMBasic firmware loaded. You just need to connect it to your PC, download the software from the *EPE* website and load it into the Micromite Plus chip.

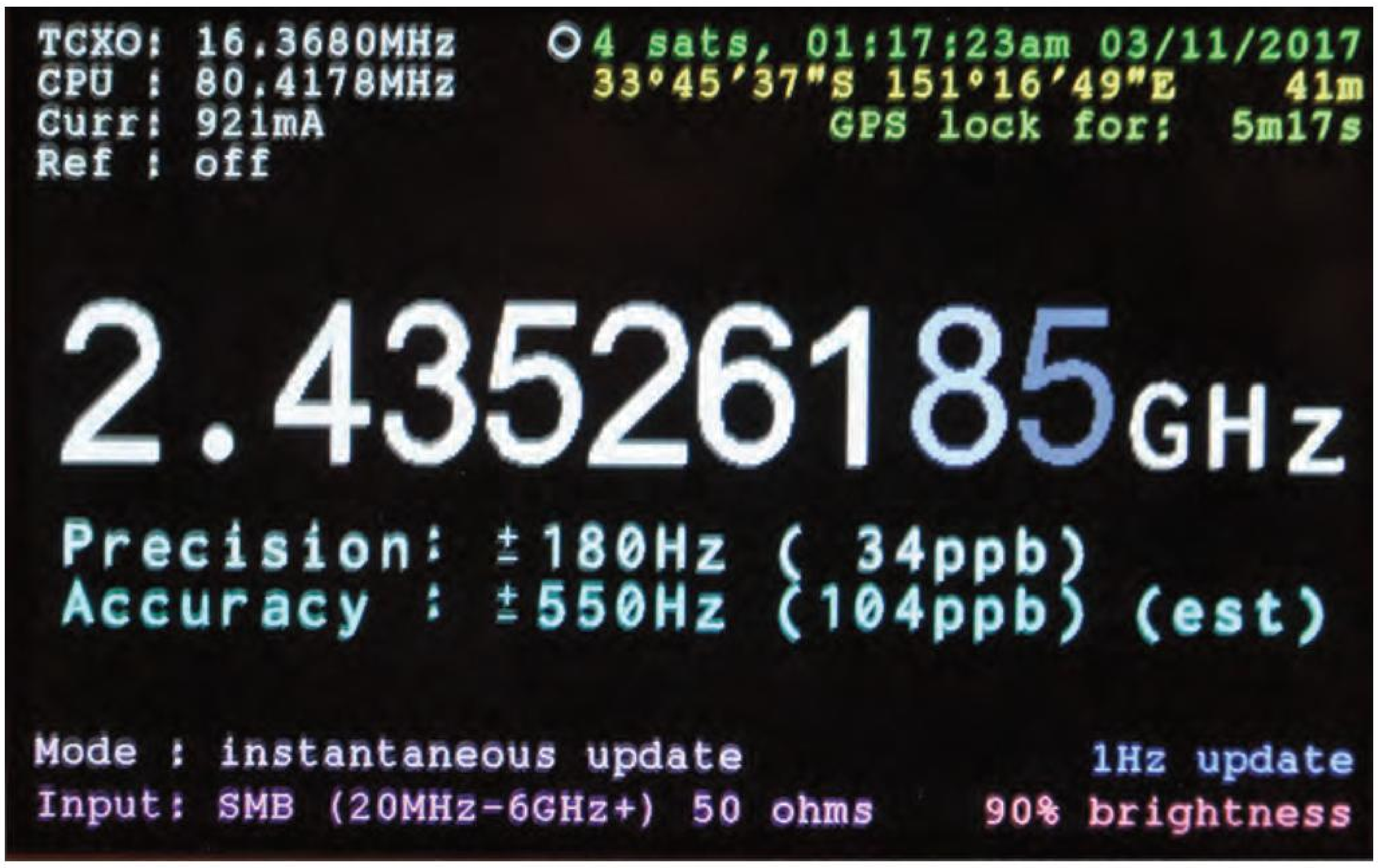
The procedures for doing that, as well as setting up the LCD touchscreen, were given in *Part 2*, last month's article.

Assuming that all went well, your unit should be operational. The rest of this article explains how to use the software and its touchscreen interface.

Main screen display

Pretty much all the functions of the *Frequency Counter* are available on the one main screen, shown in Fig.5. This is similar to the prototype screen shown in the last two articles, but with a few small tweaks as the software has been finalised.

Information is shown in each corner of the screen, plus the large frequency/period display in the centre. The frequency/period is auto-ranging, with frequency using units of mHz (millihertz), Hz, kHz, MHz or GHz and period units of ps, ns, µs, ms or s.



```
TCXO: 16.3680MHz        ○4 sats, 01:17:23am 03/11/2017
CPU : 80.4178MHz         33°45'37"S 151°16'49"E    41m
Curr: 921mA                      GPS lock for:    5m17s
Ref : off

2.43526185GHz

Precision: ±180Hz ( 34ppb)
Accuracy : ±550Hz (104ppb) (est)

Mode : instantaneous update               1Hz update
Input: SMB (20MHz-6GHz+) 50 ohms      90% brightness
```

Fig.5: the default main screen, showing the frequency reading in large digits at the centre and various additional information below that, and in the corners of the display. To change the settings in the corners, it's generally just a matter of touching that area of the screen.

You can switch between frequency and period display by touching the centre of the screen.

Changing between frequency and period display does not affect the way the measurement is being taken; both readings are calculated based on the number of pulses received from the reference clock and the input signal in a given period.

The frequency is simply calculated as F_{in}/F_{ref} while the period is F_{ref}/F_{in}.

Note that all settings, including this one, are retained in Flash memory automatically so that the configuration is retained for the next time the unit is powered up.

Accuracy and precision estimate display

Regardless of what is being displayed, the precision and accuracy estimates are shown below. Precision indicates repeatability, ie, if you measured the same exact signal using the same settings on two different occasions, this is the maximum difference you could get between the two readings.

This relates to the stability of the reference oscillator and how its frequency changes over time and with temperature.

It's computed based on the reference clock tolerance and measurement period and shown as both the parts per million/billion error and a frequency or period uncertainty.

When using averaging, the uncertainty will drop over time until it reaches a minimum value, once the programmed averaging time period has passed.

The accuracy shown automatically improves quite dramatically if you're using GPS disciplining since this will allow the unit to compensate almost entirely for long-term drift (since GPS timekeeping is much more stable) and temperature drift will also be reduced (but not eliminated).

The accuracy figure is shown in a similar manner, but this also takes into account the initial error in the reference oscillator frequency. This can be reduced if you have a more accurate reference source to calibrate the TXCO.

When using GPS disciplining, the accuracy figure will generally match the precision figure (or come close) since the accuracy provided by the GPS time signal is excellent.

Another indication of reading accuracy is the fact that the last couple of decimal places in the reading may be dimmed, indicating that they have a degree of uncertainty and even with a stable signal, you may see these digits fluctuate. If averaging is active, then over time the reading will become more certain and these digits will become lighter. With a stable signal, white digits should be quite stable.

Input switching

The current input is shown in the lower left-hand corner of the screen and you can switch inputs simply by touching it. Make sure you press far enough down the screen that you aren't pressing the Mode line above; changing mode will be explained shortly.

Mode switching is simple since it just toggles between the SMB (high-frequency) input and the BNC (low-frequency) input. If you're using averaging, it will reset when changing inputs.

The SMB input impedance is fixed at 50Ω but the BNC input impedance can be switched between 75Ω and about 1MΩ. This can be changed simply by touching that part of the Mode line when the BNC input is selected, and like the other settings, it is retained even when power is lost.

Update rate and averaging

The range of update rates has been expanded to include one update every three, two or one second or five times per second. You can cycle through these update rates by touching the update line near the lower right-hand corner of the screen.

The update rate is independent of the averaging setting. Say you select 30s averaging with a 2s update rate. You will get a reading after two seconds but it will only be based on two seconds of data.

Then you will get a reading two seconds later which will be slightly more accurate (and the accuracy and precision figures will reflect this).

The time span over which the signal has averaged so far is shown in parentheses ( ) at the end of the Mode line.

The reading accuracy will continue to improve until the 30-second mark, at which point the precision and accuracy figures will not improve. The reading will continue to change though, representing the average signal frequency over a time 'window' spanning the last 30 seconds.

In other words, the displayed value is a moving average.

If the signal frequency changes, you would have to wait 30 seconds for the new reading to be accurate. Alternatively, you can simply touch at the end of the Mode line, where the averaging time so far is displayed, to reset it to zero and start the averaging window anew.

To change the maximum window (ie, averaging) time, simply touch the left side of that line instead. This will cycle through a series of different time values from one second up to ten minutes.

To turn averaging off, you can keep pressing this until you get back to the 'immediate' setting or alternatively, to save time, hold your finger on the Mode line for a couple of seconds.

Changing the display brightness

To change the LCD backlight display brightness, press and hold your finger on the lower right-hand corner of the screen, where the current brightness percentage is displayed. While still pressing on the screen, swipe your finger up or right to increase the brightness, or left or down to decrease the brightness.

Because you're starting in the lower-right corner, it's easiest to swipe up to increase and left to decrease. But if you swipe up and increase the brightness too much, you can go either down or left to bring it back to the desired value.

Reducing the brightness to the minimum will drop power consumption by around 200-250mA compared to maximum brightness. The estimated current drawn from the DC supply for a given configuration is shown in the upper-left corner of the screen.

Frequency reference calibration

The upper-left corner also shows the TCXO frequency and measured CPU (PIC32) operating frequency.

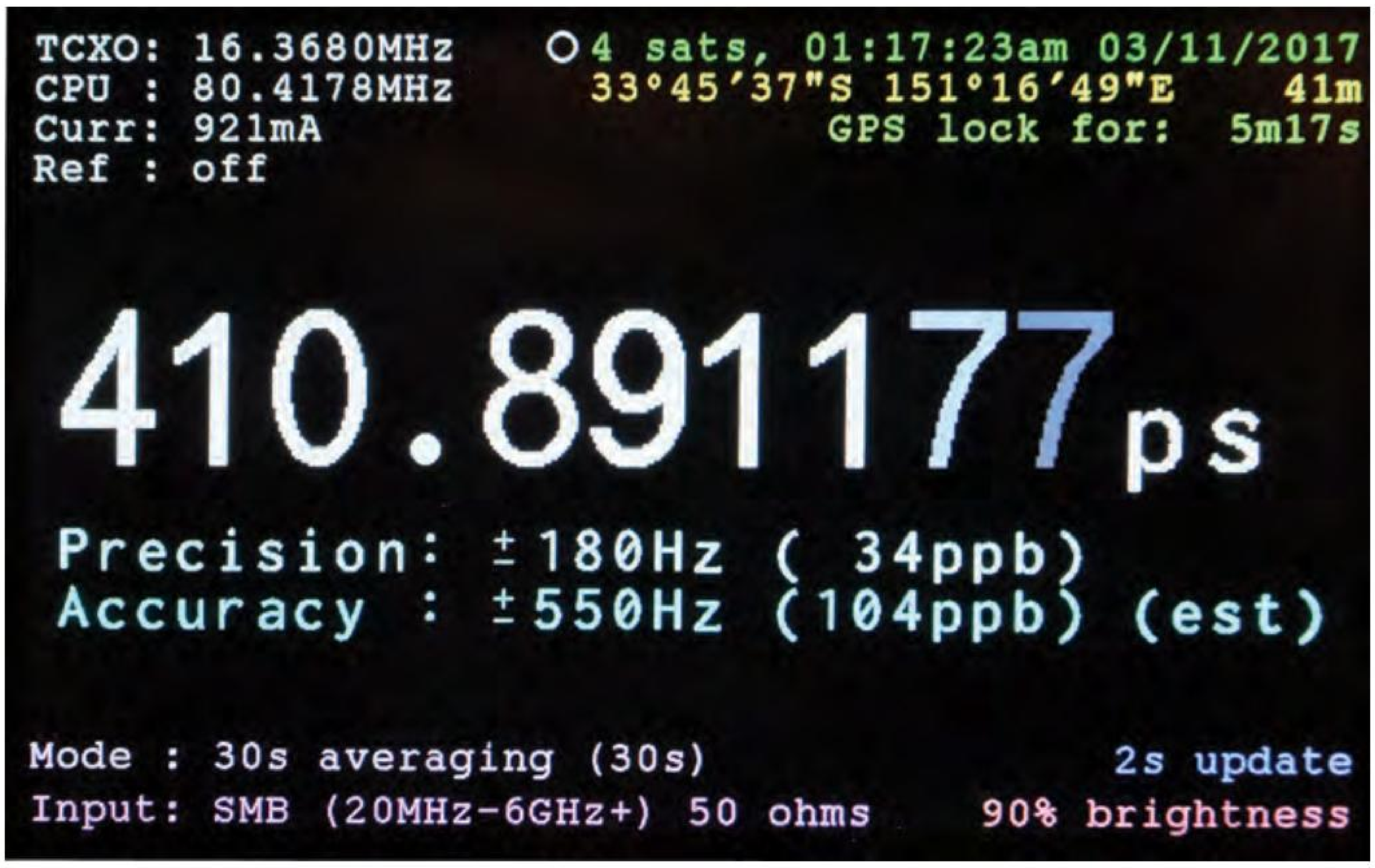
The latter is mainly for interest's sake. The CPU is typically operated at 80MHz as a compromise between screen update speed and power consumption/stability.

The PIC32 itself is perfectly stable at higher speeds, but we saw some display glitches when driving the touchscreen at faster rates (the LCD bus speed is determined by the CPU clock rate).

The TCXO specified operates at a nominal 16.368MHz and this will be the default value at power-up. It can change for two reasons: either you've manually calibrated it (as described below) or the GPS 1PPS signal has been used to determine the actual TCXO frequency. So when GPS disciplining is available, the TCXO setting automatically updates when necessary.

These changes are saved to the PIC32's Flash memory so that the frequency can be accurate the next time the unit is powered up before it's been running long enough to get an accurate reading of the GPS time base.

For manual calibration (eg, if you have not fitted a GPS unit), you must first measure the TCXO frequency.



```
TCXO: 16.3680MHz    ○ 4 sats, 01:17:23am 03/11/2017
CPU : 80.4178MHz      33°45'37"S 151°16'49"E    41m
Curr: 921mA               GPS lock for:   5m17s
Ref : off

410.891177ps

Precision: ±180Hz ( 34ppb)
Accuracy : ±550Hz (104ppb) (est)

Mode : 30s averaging (30s)               2s update
Input: SMB (20MHz-6GHz+) 50 ohms    90% brightness
```

Fig.6: a similar display but this time with the output shown as a period rather than a frequency, and with averaging enabled. Most of the operation and interaction with the unit is done via this screen.

Micromite parts and competition!

We recommend you make **micromite.org** your first port of call when shopping for all Micromite project components. Phil Boyce, who runs micromite.org, can supply kits, programmed ICs, PCBs and many of the sensors and other devices mentioned in recent articles.

Last, but not least, do see page 31 for an exciting Micromite competition!

There are three ways to do this. The first is the simplest but needs to be done with the case open and requires an accurate frequency meter. It needs to be more accurate than the one you are calibrating, eg, around 1ppm or ±0.0001% accuracy or better.

Measure the frequency at pin 9 of the Explore 100 header, relative to pin 1 (ground). Then press on the TCXO frequency at upper-left and hold your finger down for a couple of seconds, then lift it.

A keypad will appear and you can enter the precise TCXO frequency in Hz.

It will then ask you for a second figure, the accuracy of your frequency meter, in ppb (parts per billion). 1ppm = 1000ppb = 0.0001%. This is used to provide the estimated precision and accuracy figures when making a measurement.

If you don't know, abort entering this number and the default value for an uncalibrated TCXO will be used, but the calibration itself will still be performed.

The new figures will be stored and displayed but you can recalibrate again at a later date if necessary.

The second option can be done with the case closed – all you need is an accurate frequency source. You could use the 10MHz reference output from another piece of test equipment.

Make sure the TCXO frequency is set to the default value of 16.368MHz; if not, set it using the above procedure.

Feed the signal in and measure its frequency with reasonably long averaging (eg, one minute). Take note of the figure shown on the screen. Let's call it F_{meas} and the expected frequency F_{exact}. Now perform the following calculation, with all values in Hz:

TCXO = 16368000 x F_{exact} / F_{meas}

You can now program the resulting figure in as the new measured TCXO frequency using the procedure given above. If you know the accuracy of your reference signal frequency, enter that in when prompted for the 'ppb' figure (in parts per billion).

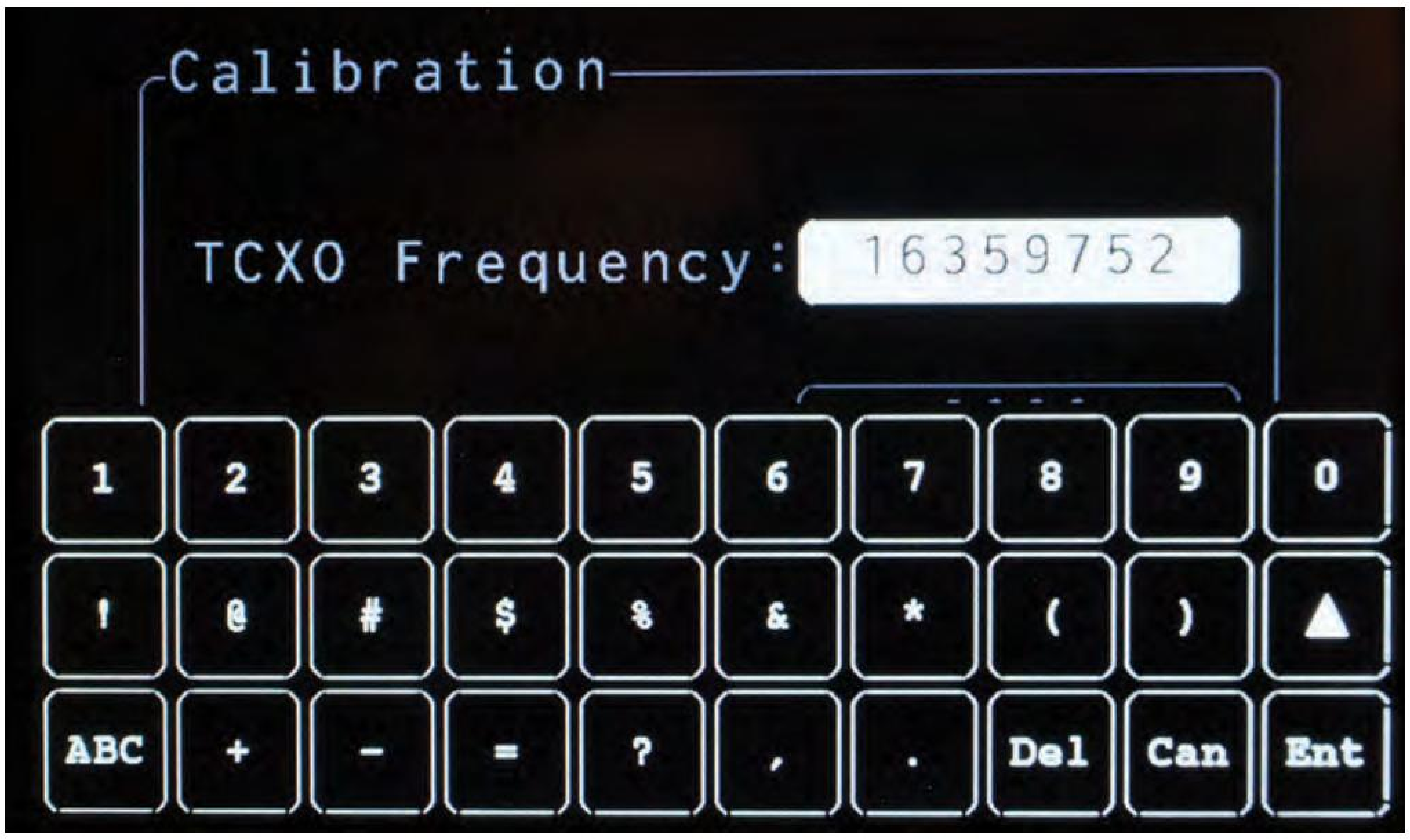
The third method is a combination of the above two methods and requires a stable (but not necessarily accurate) frequency source along with an accurate frequency meter.

You simply measure the frequency of your signal source using the accurate meter, then feed that same signal into your newly built *Frequency Meter* and measure it as stated immediately above.

You can then perform the same calculation, using the figure you got from your known-accurate meter in place of F_{exact} and the figure from your new *Meter* as F_{meas}. As before, the accuracy (ppb) figure should reflect the accuracy of the meter you're using for calibration.

GPS disciplining

If you fit a GPS module, this is all pretty much automatic. The PIC32 should detect a valid serial stream from the GPS unit and display some figures in the upper-right corner of the screen. If not, check that you haven't transposed the TX and RX pins of the GPS unit or made some other mistake with the wiring. Check also that the power LED on your GPS unit is lit.



TCXO Frequency: 16359752

Fig.7: using the on-screen keypad to calibrate the onboard oscillator for greater accuracy. There are three different calibration methods given in the text, with the simplest involving measuring the oscillator frequency with a more accurate meter and then typing it in as shown here.

Most GPS units (including the recommended VK2828) also have an LED which flashes when it has a good satellite lock.

If you're getting some indication in the upper-right corner that the GPS unit has been detected but you aren't seeing a proper fix (latitude, longitude, time, date) then you may need to move the unit closer to a window or consider fitting a GPS module with an external antenna.

Note that it may take several minutes to get a lock even with a good signal, especially if the GPS module has not been used for many days.

Once a signal has been found, a circle is displayed which should flash at 1Hz, concurrent with the 1PPS signal from the GPS unit. It will be red if a satellite lock has not yet been achieved or green if it has.

Once it's green, the unit will start internally 'time stamping' each pulse. If the lock remains good for at least a few minutes, the time stamps will be used to improve the TCXO frequency and thus the reading accuracy and precision.

The length of time that the unit has had a good satellite lock is shown below the latitude, longitude and altitude information (which are provided merely for your curiosity).

Also, it's important to realise that the time and date given are for UTC (GMT).

They're also provided for your reference; you need to know your current local time zone offset to convert them to local time.

By the way, we suggest once you get the *Meter* up and running, you leave it in a location with a good GPS signal lock and leave it powered up for at least half an hour to allow it to calibrate the TCXO frequency to a reasonable accuracy.

If you're only using it in short bursts later, it may not have enough time to get a good lock and so doing this periodically (eg, every couple of months) will help it continue to provide good accuracy.

Reference output

As stated in the earlier articles, the reference (BNC) output can produce one of three signals: a fixed 1Hz or 1kHz reference signal, or a frequency

```
SILICON CHIP 6GHz+ Touchscreen Frequency/Period Meter
Timestamp,Hz,Freq,PrecHz,AccHz,TCXO,Input,Imped,Mode,AvgSec,GPSSats,UTC,Date
6239317,5260135255,5.26013526GHz,240,370,16367993,SMB,50,1,5,124837,03112017
6239817,5260134170,5.26013417GHz,230,360,16367993,SMB,50,1,5,124837,03112017
6240317,5260134285,5.26013429GHz,220,350,16367993,SMB,50,1,5,124838,03112017
6240817,5260133925,5.26013393GHz,210,340,16367993,SMB,50,1,5,124838,03112017
6241317,5260133910,5.26013391GHz,200,330,16367993,SMB,50,1,5,124839,03112017
6241817,5260133965,5.26013397GHz,200,330,16367993,SMB,50,1,5,124839,03112017
6242317,5260133940,5.26013394GHz,195,325,16367993,SMB,50,1,5,124840,03112017
6242817,5260133995,5.26013400GHz,190,320,16367994,SMB,50,1,5,124840,03112017
6243317,5260133965,5.26013397GHz,190,320,16367994,SMB,50,1,5,124841,03112017
```

Table 1: sample output from the unit over the serial console, captured with a terminal emulator. The result is in a CSV format so you can save, plot and analyse it easily using standard software such as Microsoft Excel or LibreOffice/OpenOffice Calc.

that is equal to the measured frequency divided by 1000 (for the BNC input) or 1,000,000 (for the SMB input).

This varying division ratio is necessary to keep the output frequency within reason at the upper end of the device's measurement range and is shown on-screen when you switch inputs. You still just need to substitute the units when reading the divided output to get the actual frequency.

Note that while the average frequency produced from the reference output should be very accurate, there could be some jitter because of the 'pulse diffusion' technique used to provide an accurate division ratio. So it's best to feed it to equipment with a reasonably long acquisition window (say at least 100ms) to get good results.

Serial output

One feature we haven't mentioned so far is that the measured frequency/period, TCXO oscillator frequency and general configuration are also printed to the serial console in CSV format. So if you want to hook the *Meter* up to your PC, you can do so and capture/log/process the resulting data quite easily.

You can see the output of the unit in MMEdit's 'MMChat' window or you could use a serial console program like Tera Term Pro to view and capture this data. Set its baud rate to 115,200 and make sure the correct COM port is selected. Make sure to close MMEdit before launching Tera Term Pro so that the COM port isn't already in use. Once captured, save the data to a CSV file so you can open it later for analysis.

Conclusion

Despite all the previous explanation, this *Meter* is quite simple to use, especially if you are using GPS disciplining since there is no need for manual calibration.

All you need to do is connect your signal up to one of its inputs, power it up, select the appropriate input and averaging time, then wait a few seconds and read off the result.

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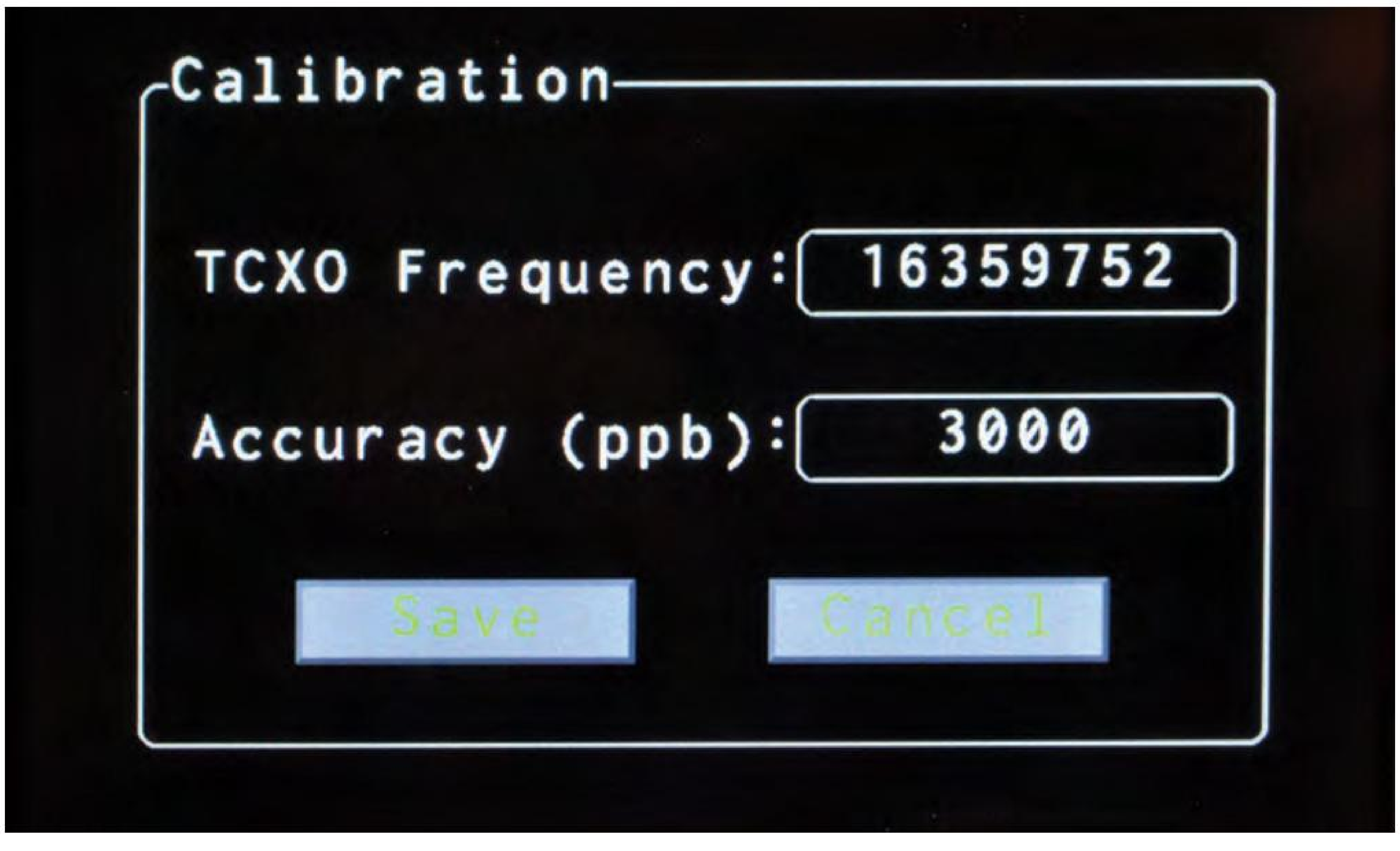

TCXO Frequency: 16359752

Accuracy (ppb): 3000

Fig.8: having entered the measured TCXO frequency, you also have the option of providing an accuracy figure to go along with it. This allows the unit to compute and display the new, better accuracy figure for any given reading. Press the Save button and the new calibration figures will take effect.

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software download please visit
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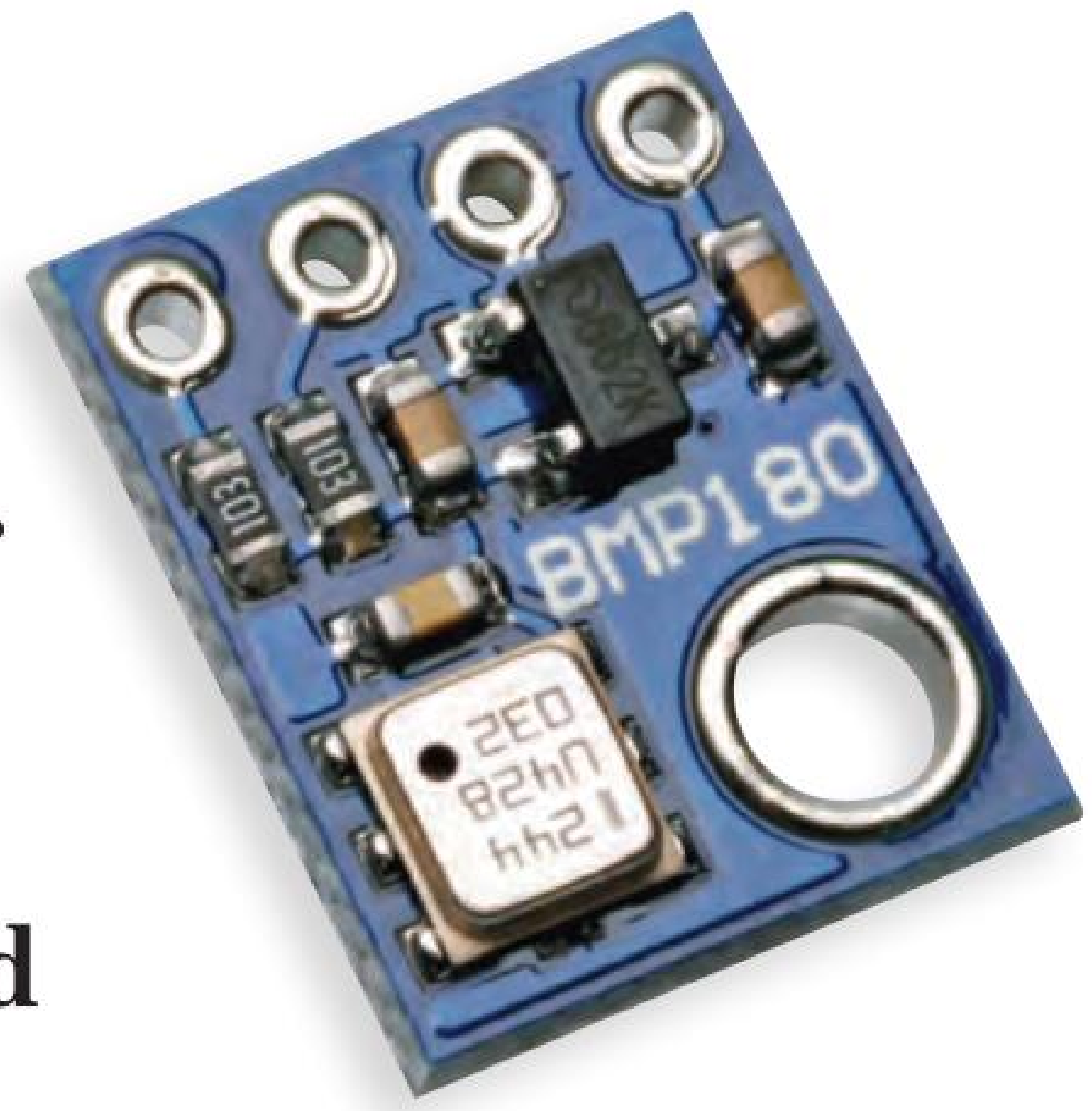
Using Cheap Asian Electronic Modules Part 11: by Jim Rowe

Elecrow GY-68 & GY-BM Barometer/Temperature Sensor Modules



This month, we're looking at two very tiny modules which sense barometric pressure and air temperature. One uses the Bosch BMP180 digital pressure sensor, while the other uses the newer BMP280 sensor. Both can send their readings to virtually any micro via a standard I^{2}C serial interface, while the BMP280-based module also offers an SPI interface.

The first thing you notice about the Elecrow GY-68 digital barometer module is its tiny physical size. It measures only 13 × 10 × 2.5mm, making it by far the smallest module we've looked at so far in these articles. The BMP180 sensor IC, which forms the functional heart of the module is much smaller again, measuring only 3.6 × 3.8 × 0.93mm.

The BMP180 has what is described as ultra-low-power consumption, drawing less than 10µA when taking readings once per second and less than 1µA in standby mode. Clearly, it's very suitable for use in compact portable devices like smartphones.

It's also a low-cost device. The Elecrow GY-68 module we're looking at here is available from Banggood, AliExpress and eBay.

The BMP180 sensor

This is made by Bosch Sensortec, a division of the large German firm Robert Bosch GmbH (**www.bosch-sensortec.com**). The BMP180 is based on piezo-resistive MEMS technology, where MEMS stands for 'MicroElectroMechanical Systems'. In other words, it uses a tiny sensor element which flexes mechanically in response to changes in atmospheric pressure and the flexing is sensed by measuring changes in the element's resistance.

The BMP180's 3.6 × 3.8 × 0.93mm metal package has a tiny vent hole (about 0.5mm diameter) in the top to allow the sensor element access to the outside air. And apart from the sensor element, there are three other functional blocks inside the device.

As shown in Fig.1, the three blocks comprise an ADC (analogue-to-digital converter) to make the measurements, a control unit which also provides the I^{2}C serial interface for communicating with an external micro and an EEPROM which has 22 bytes of storage for the device's 11 × 16-bit calibration parameters.

Every individual BMP180 device is calibrated during manufacture, after which the calibration parameters are saved in its EEPROM. An external micro can read these parameters and use them to correct that sensor's readings for offset, temperature dependence and other factors.

So with suitable software, the BMP180 can provide very high accuracy measurements of both barometric pressure and temperature. The relative accuracy for pressure is quoted as ±0.12hPa from 950-1050hPa at 25°C, while the absolute accuracy is quoted as –4 to +2hPa over the range from 300-1100hPa and for temperatures of 0-65°C. Impressive!

With the right software, it's also fairly easy to use the BMP180 as an altimeter, capable of indicating your current altitude above mean sea level (MSL). So its applications are not limited to being used as a barometer and thermometer.

By the way, although the BMP180 normally comes with the I^{2}C serial interface, a variant is also available with an SPI interface. Presumably, this would be for large orders from equipment manufacturers.

Incidentally, if you're unfamiliar with barometers and the various units used for atmospheric or barometric pressure, you might like to refer to the panel headed 'Barometric Pressure and Units'.

Elecrow's GY-68 module

As you can see from the photo of the Elecrow module, there are few components apart from the BMP180 sensor itself: just an SOT-23 low-dropout (LDO) voltage regulator, three surface-mount capacitors and two resistors.

Fig.2 shows its complete circuit. REG1 is the MCP1700 3.3V LDO regulator, used to ensure that the supply voltage for the BMP180 is kept within its ratings (3.6V max). It also ensures that the two pull-up resistors on the I^{2}C interface's SDA and SCL are returned to the same safe voltage level. The three capacitors are for supply-rail bypassing.

CON1 is the 4-pin connector used both to supply the module with its power and also to connect to an external micro via the I^{2}C interface. Since the module draws less than 10µA from the supply when it's taking one measurement per second, there's no problem in powering it from an Arduino or a Micromite module, or from a power bank using a 3.7V Li-ion cell.

Connecting it to a micro

Fig.3 shows a simple way of connecting the GY-68 barometer module to an

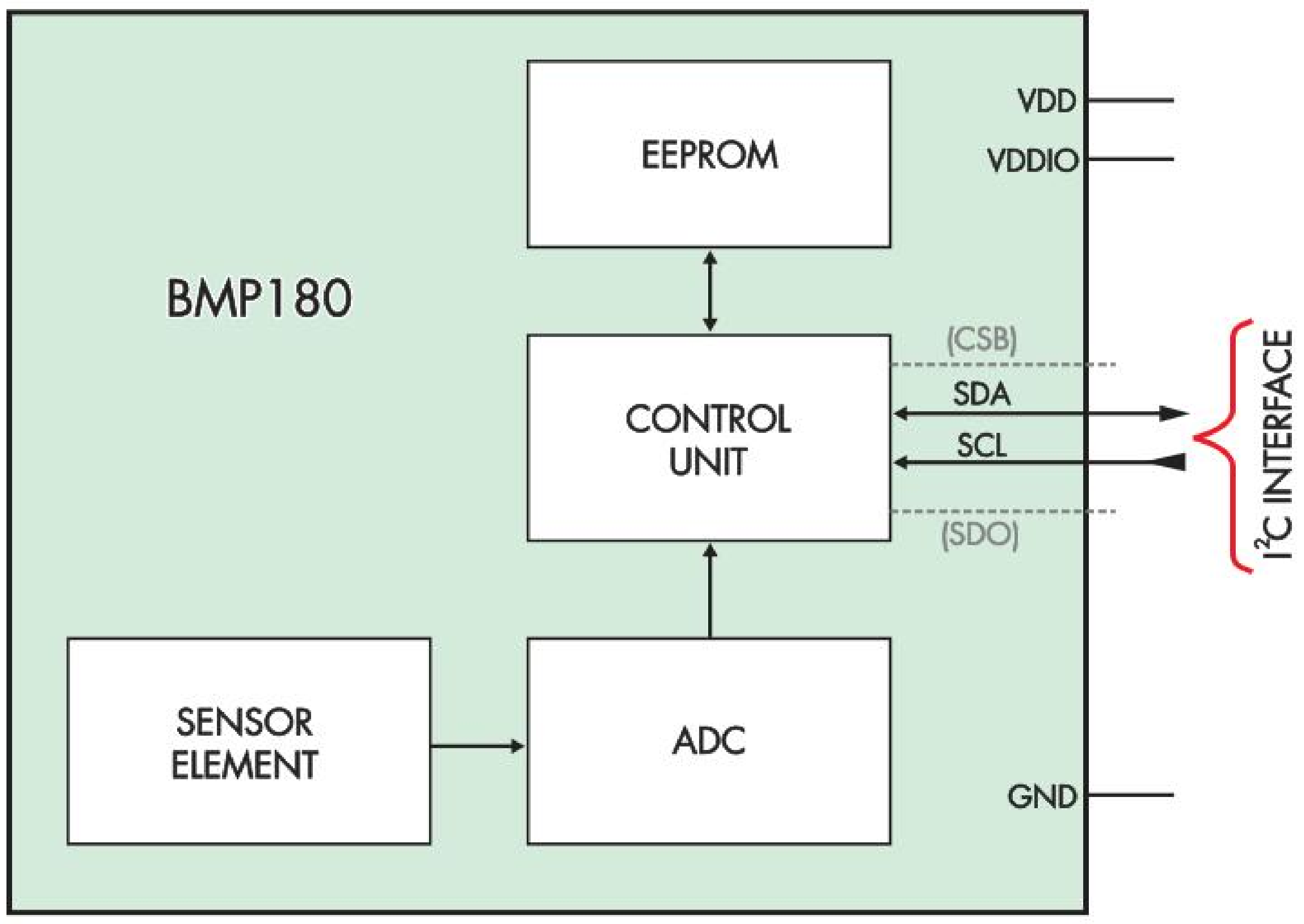


Fig.1: block diagram of the BMP180 (the small metal package located on the module). It contains 22 bytes of EEPROM for storing calibration values.

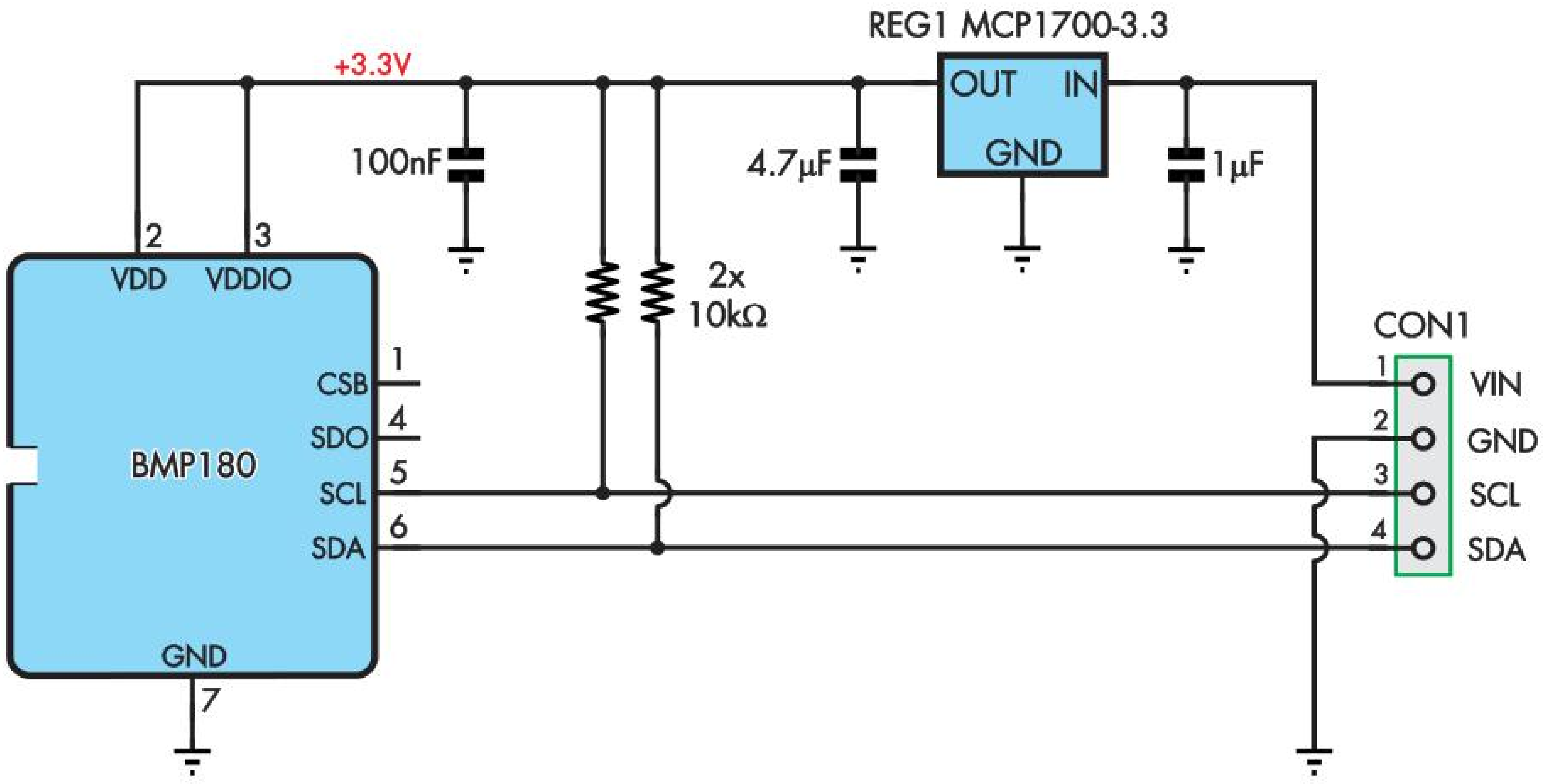


Fig.2: complete circuit for the GY-68 module. CON1 provides power and I²C interfacing for the module, which draws less than 10μA when taking readings, and 1μA in standby mode.

Arduino. The SCL and SDA lines of the GY-68 connect to the SCL/A5 and SDA/A4 pins of the Arduino, while the V_{IN} and GND lines connect to the +5V and GND pins respectively. That's all there is to it.

It's equally simple to connect the module to a Micromite, as you can see from Fig.4. Here the SCL and SDA lines connect to pins 17 and 18 of the Micromite respectively, while as before, the V_{IN} and GND lines go to +5V and GND.

Programming it

It's relatively easy to get the GY-68 module working happily with an Arduino, although this does involve the use of a matching software library called **SFE_BMP180.zip**. This can be downloaded from the Elecrow website at **https://github.com/sparkfun/BMP180_Breakout**

After downloading, it can be added to the libraries in your Arduino IDE by clicking on Sketch → Include Library → Add .ZIP Library and then directing it to the folder into which the zip file was downloaded.

On the *EPE* website, you can find a small sketch for running the GY-68/BMP180 with an Arduino, called **SFE_BMP180_barometer_sketch.ino**. I have adapted it from a sample sketch provided by Elecrow.

It's pretty straightforward, first initialising the BMP180 (ie, extracting the calibration parameters from its EEPROM) and then taking a measurement of temperature and barometric pressure every five seconds.

Each time it takes a measurement, it crunches the data and displays the results on the Arduino IDE's Serial Monitor. A sample of this is shown in the screen grab of Fig.5.

Since the BMP180 only measures the temperature and absolute air pressure, the sketch needs to know your current altitude above sea level in order to calculate the corresponding MSL pressure. This information is fed to it in this line, located very close to the start of the sketch:

```
#define ALTITUDE 55.0
```

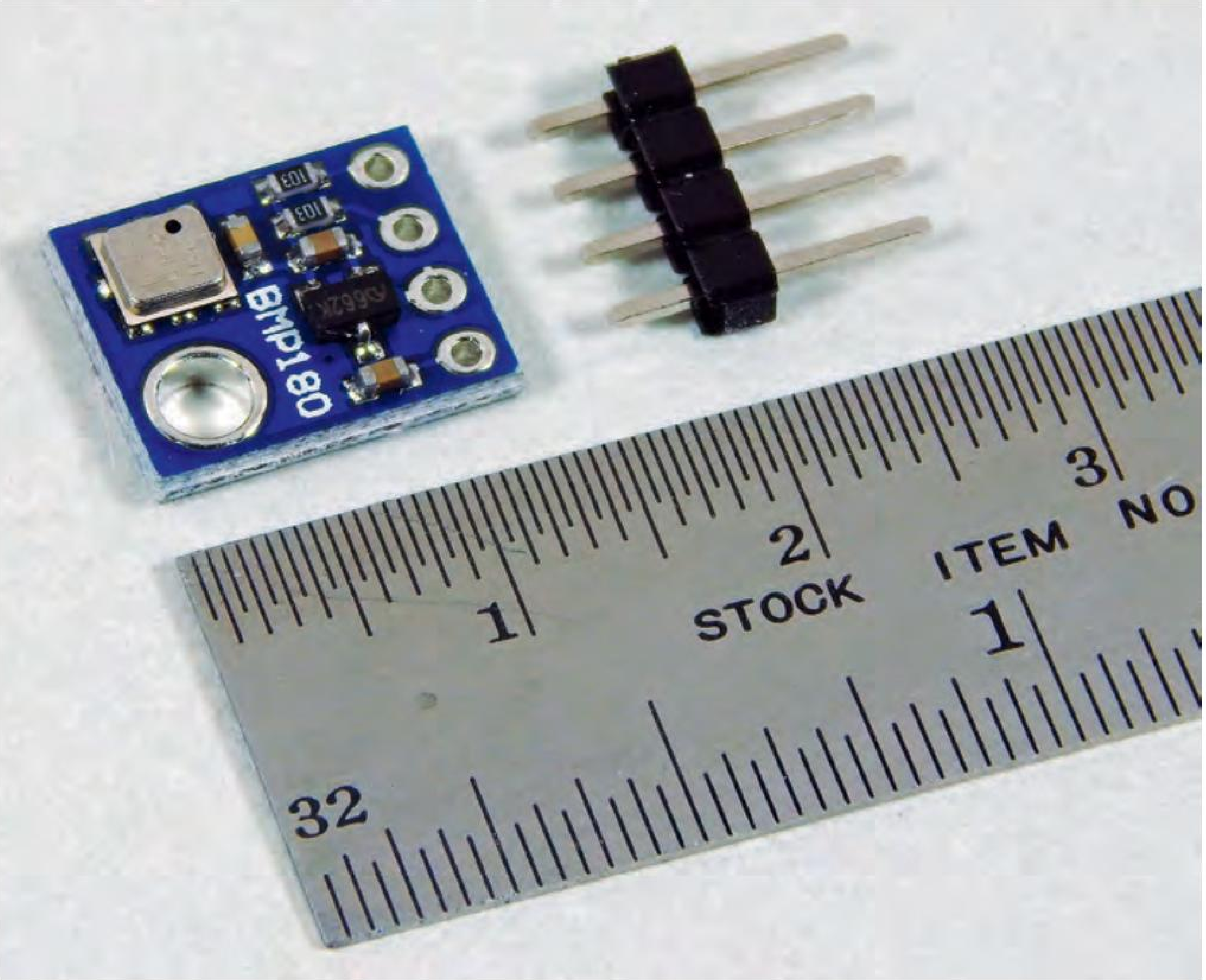
This sets the altitude to 55 metres, which is a rough estimate of my workbench's altitude above MSL. However, as the comment on the right of this line explains, you can easily substitute your own altitude if you want maximum accuracy.

You'll note from Fig.5 that the sketch repeats this altitude figure in the first line of each set of measurements, giving it in both metres and feet. It also shows the temperature reading in both degrees Celsius and degrees Fahrenheit as well as the absolute and MSL-relative pressures in both millibars and inHg (inch of mercury; reflecting its origin in the US).

Finally, it repeats the altitude figures again, but this time describes them as 'computed altitude'. This sketch is a good way to see what the GY-68 module can do.

It's not quite so easy to get the GY-68 module working with a Micromite because there is no pre-existing or built-in library designed to communicate with it and do the calculations to provide the corrected temperature and pressures.

However, I have written an MMBasic program to do the job and you can download it (**BMP180 barometer check prog.bas**) from the *EPE* website.



The Elecrow GY-68 module is shown here at three times actual size, as it is only 13 × 10mm. The metal package BMP180 sensor (3.6 × 3.8mm) is based on piezoresistive MEMS technology.

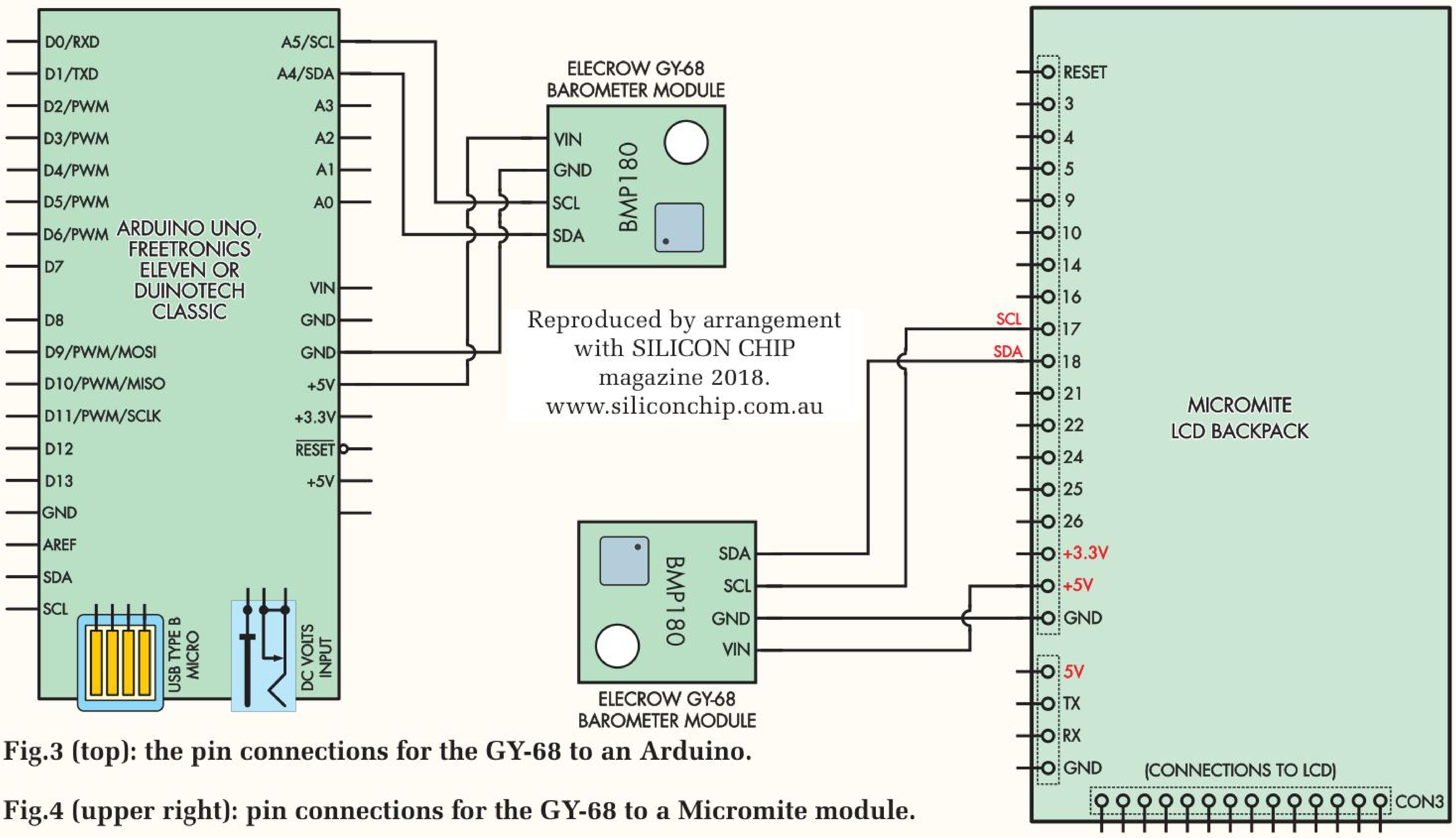

D0/RXD
D1/TXD
D2/PWM
D3/PWM
D4/PWM
D5/PWM
D6/PWM
D7
D8
D9/PWM/MOSI
D10/PWM/MISO
D11/PWM/SCLK
D12
D13
GND
AREF
SDA
SCL
ARDUINO UNO, FREETRONICS ELEVEN OR DUINOTECH CLASSIC
A5/SCL
A4/SDA
A3
A2
A1
A0
VIN
GND
GND
+5V
+3.3V
RESET
+5V
USB TYPE B MICRO
DC VOLTS INPUT
ELECROW GY-68 BAROMETER MODULE
VIN
GND
SCL
SDA
BMP180
SDA
SCL
GND
VIN
BMP180
ELECROW GY-68 BAROMETER MODULE
SCL
SDA
RESET
3
4
5
9
10
14
16
17
18
21
22
24
25
26
+3.3V
+5V
GND
5V
TX
RX
GND
(CONNECTIONS TO LCD)
CON3
MICROMITE LCD BACKPACK

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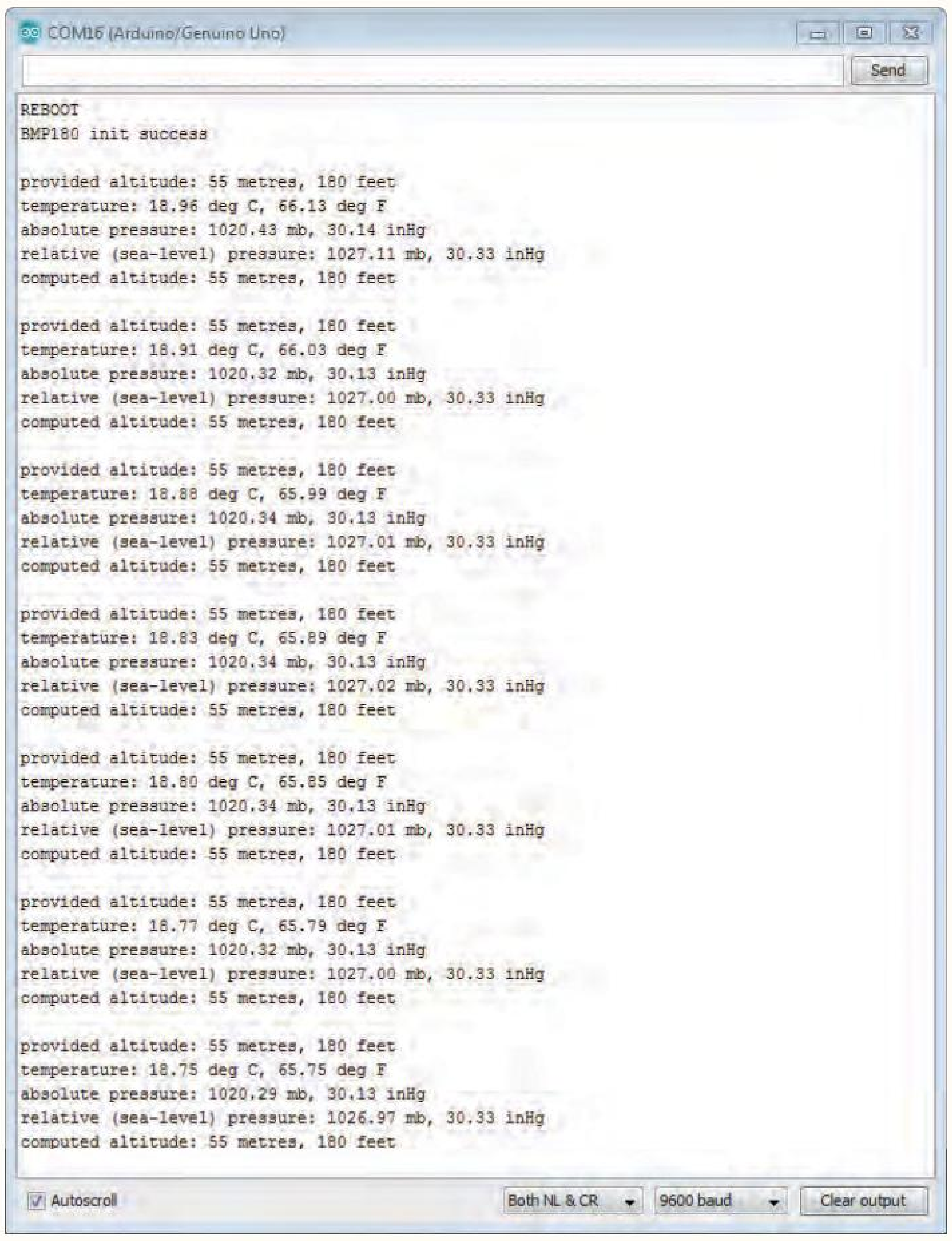
Fig.3 (top): the pin connections for the GY-68 to an Arduino.

Fig.4 (upper right): pin connections for the GY-68 to a Micromite module.

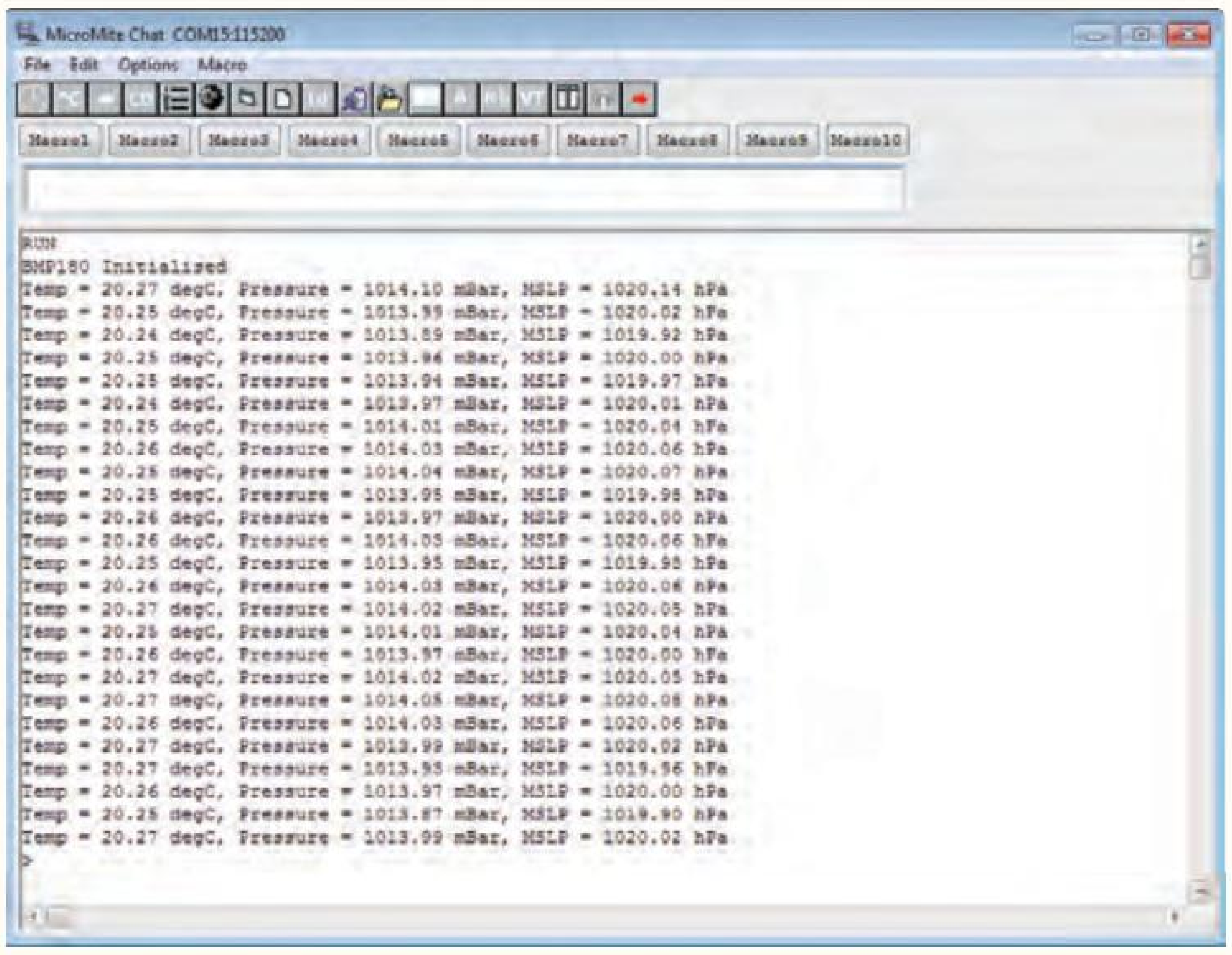
Fig.5 (bottom left): example data from the GY-68 sensor module when connected to an Arduino.

Fig.6 (opposite right): example data from the module when connected to a Micromite.

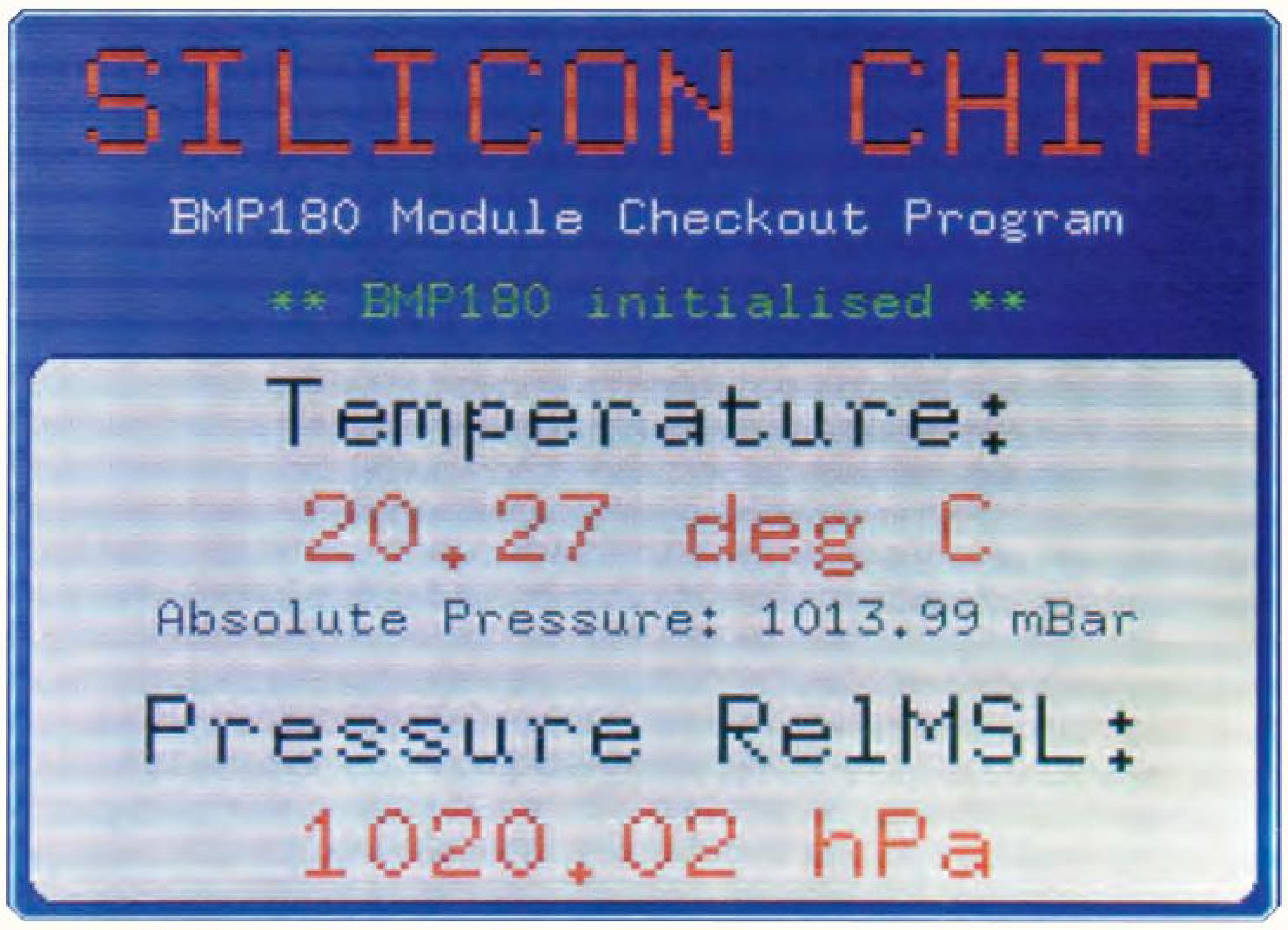
Fig.7 (bottom right): when running the Micromite sample software, if there is a screen attached, it will also show the readings on the display.


COM16 (Arduino/Genuino Uno)
Send
Autoscroll
Both NL & CR
9600 baud
Clear output

```
REBOOT
BMP180 init success

provided altitude: 55 metres, 180 feet
temperature: 18.96 deg C, 66.13 deg F
absolute pressure: 1020.43 mb, 30.14 inHg
relative (sea-level) pressure: 1027.11 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet

provided altitude: 55 metres, 180 feet
temperature: 18.91 deg C, 66.03 deg F
absolute pressure: 1020.32 mb, 30.13 inHg
relative (sea-level) pressure: 1027.00 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet

provided altitude: 55 metres, 180 feet
temperature: 18.88 deg C, 65.99 deg F
absolute pressure: 1020.34 mb, 30.13 inHg
relative (sea-level) pressure: 1027.01 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet

provided altitude: 55 metres, 180 feet
temperature: 18.83 deg C, 65.89 deg F
absolute pressure: 1020.34 mb, 30.13 inHg
relative (sea-level) pressure: 1027.02 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet

provided altitude: 55 metres, 180 feet
temperature: 18.80 deg C, 65.85 deg F
absolute pressure: 1020.34 mb, 30.13 inHg
relative (sea-level) pressure: 1027.01 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet

provided altitude: 55 metres, 180 feet
temperature: 18.77 deg C, 65.79 deg F
absolute pressure: 1020.32 mb, 30.13 inHg
relative (sea-level) pressure: 1027.00 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet

provided altitude: 55 metres, 180 feet
temperature: 18.75 deg C, 65.75 deg F
absolute pressure: 1020.29 mb, 30.13 inHg
relative (sea-level) pressure: 1026.97 mb, 30.33 inHg
computed altitude: 55 metres, 180 feet
```


MicroMite Chat COM15:115200
File
Edit
Options
Macro
Macro1
Macro2
Macro3
Macro4
Macro5
Macro6
Macro7
Macro8
Macro9
Macro10

```
RUN
BMP180 Initialised
Temp = 20.27 degC, Pressure = 1014.10 mBar, MSLP = 1020.14 hPa
Temp = 20.25 degC, Pressure = 1013.99 mBar, MSLP = 1020.02 hPa
Temp = 20.24 degC, Pressure = 1013.89 mBar, MSLP = 1019.92 hPa
Temp = 20.25 degC, Pressure = 1013.96 mBar, MSLP = 1020.00 hPa
Temp = 20.25 degC, Pressure = 1013.94 mBar, MSLP = 1019.97 hPa
Temp = 20.24 degC, Pressure = 1013.97 mBar, MSLP = 1020.01 hPa
Temp = 20.25 degC, Pressure = 1014.01 mBar, MSLP = 1020.04 hPa
Temp = 20.26 degC, Pressure = 1014.03 mBar, MSLP = 1020.06 hPa
Temp = 20.25 degC, Pressure = 1014.04 mBar, MSLP = 1020.07 hPa
Temp = 20.25 degC, Pressure = 1013.95 mBar, MSLP = 1019.98 hPa
Temp = 20.26 degC, Pressure = 1013.97 mBar, MSLP = 1020.00 hPa
Temp = 20.26 degC, Pressure = 1014.03 mBar, MSLP = 1020.06 hPa
Temp = 20.25 degC, Pressure = 1013.95 mBar, MSLP = 1019.98 hPa
Temp = 20.26 degC, Pressure = 1014.03 mBar, MSLP = 1020.06 hPa
Temp = 20.27 degC, Pressure = 1014.02 mBar, MSLP = 1020.05 hPa
Temp = 20.25 degC, Pressure = 1014.01 mBar, MSLP = 1020.04 hPa
Temp = 20.26 degC, Pressure = 1013.97 mBar, MSLP = 1020.00 hPa
Temp = 20.27 degC, Pressure = 1014.02 mBar, MSLP = 1020.05 hPa
Temp = 20.27 degC, Pressure = 1014.05 mBar, MSLP = 1020.08 hPa
Temp = 20.26 degC, Pressure = 1014.03 mBar, MSLP = 1020.06 hPa
Temp = 20.27 degC, Pressure = 1013.99 mBar, MSLP = 1020.02 hPa
Temp = 20.27 degC, Pressure = 1013.93 mBar, MSLP = 1019.96 hPa
Temp = 20.26 degC, Pressure = 1013.97 mBar, MSLP = 1020.00 hPa
Temp = 20.25 degC, Pressure = 1013.87 mBar, MSLP = 1019.90 hPa
Temp = 20.27 degC, Pressure = 1013.99 mBar, MSLP = 1020.02 hPa
>
```


SILICON CHIP
BMP180 Module Checkout Program
** BMP180 initialised **
Temperature:
20.27 deg C
Absolute Pressure: 1013.99 mBar
Pressure RelMSL:
1020.02 hPa

This program expects a GY-68/BMP180 to be connected to the Micromite, as shown in Fig.4, so once you do this and upload the program, it should spring into life.

If you have the Micromite still connected to your PC and have Micromite Chat open, you'll see that it produces temperature and pressure measurements every second, as shown in the screen grab of Fig.6. Just as with the Arduino sketch, this program also needs to know your current altitude/elevation in order to work out the equivalent barometric pressure at MSL.

As before, you need to substitute your elevation in this line, which you'll find near the start of the program and in about the middle of the declaration of the program's variables:

```
DIM AS INTEGER Alt = 50
```

Simply substitute your own altitude/elevation above MSL (in metres) instead of the '50' in this line, then upload the program to the Micromite and get it going (by clicking on the little 'gearwheel' button in the Micromite Chat toolbar). It will then show the current mean-sea-level pressure (MSLP) as the last item in each line.

If your Micromite is hooked up to an LCD touchscreen, it will also give you an on-screen display of the temperature and pressure readings, as shown in the screen shot of Fig.7. Like the measurements sent back to your PC, the display is updated every second.

Incidentally, I compared the temperature and pressure readings achieved using this program with the figures shown on the Australian Government Bureau of Meteorology website (which updates every 10 minutes in the Sydney area where I work), and they compared surprisingly well. The temperature was within 0.2°C and the MSL pressure within 0.5hPa; not bad at all for such a small device!

If you want to make your own comparisons, you'll find local information at: **www.myweather2.com**

Just enter your city, town or postcode and you'll see a list of current weather data, including local temperature and MSLP.

The new GY-BM module

Elecrow have recently added a second digital Barometer/Temperature module to their range: the GY-BM module, based on Bosch Sensortec's new BMP280 digital sensor IC.

The new module is only slightly larger than the GY-68, but it is still very small – measuring only 15 × 11 × 3mm. On the other hand, the BMP280 sensor IC itself is even smaller than the BMP180, measuring only 2.0 × 2.5 × 0.95mm.

Despite this tiny size the BMP280 offers some advantages over the BMP180. These include a dual-mode SPI interface (modes '00' or '11') in addition to the I^2C interface, higher measurement resolution for both pressure (0.16Pa vs 1Pa) and temperature (0.01°C vs 0.1°C), lower current consumption (2.7µA vs 12µA) and an internal software configurable IIR filter to allow minimisation of short-term air pressure disturbances.

In terms of absolute accuracy, the BMP280 is essentially identical to the BMP180. Pressure accuracy is ±1hPa from 0-65°C, while the temperature accuracy is ±0.5°C at 25°C and ±1.0°C from 0-65°C.

The internals of the BMP280 appear to be very similar to those of the BMP180 shown in Fig.1, apart from it being provided with an SPI interface as well as the I^2C interface. The calibration parameters are again stored in a 22-byte internal EEPROM/NVM (non-volatile memory) during manufacture.

The circuit of the GY-BM module is shown in Fig.8, and as you can see it's even simpler than that of the GY-68 module shown in Fig.2. That is because the GY-BM module is intended to run only from a nominal 3.3V supply, and as a result it has no on-board LDO (low dropout) regulator.

On the other hand, it has a six-pin connector (CON1) compared to the four pins of the GY-68. The two extra pins are required because the optional SPI interface requires four pins, compared to just two for the I^2C interface.

To connect the GY-BM module to a micro using the I^2C interface, the SDA line should be connected to pin 6 of CON1, while the SCL line is connected to pin 3.

Additionally, the CSB pin (CON1 pin 5) should be left floating, so it's pulled high via the 10kΩ pullup resistor – this signals to the BMP280 that the I^2C interface is to be used.

Finally, pin 4 of CON1 can be used to set the module's I^2C address, connecting it to ground to give it the same 'default' address as the BMP180, or connecting it to V_{IN} (+3.3V) to give it a different address.

However, if you want to connect the GY-BM module to a micro using a standard four-wire SPI interface, the SDI line should be connected to pin

Barometric pressure and units

You'll find quite a few units in use for measuring atmospheric or barometric pressure: pascals (Pa) and hectopascals (hPa), bars (B) and millibars (mB), millimetres of mercury (mmHg) and inches of mercury (inHg).

Basically, atmospheric pressure is due to the weight of air immediately above you and it corresponds to a force per unit area. The primary SI unit for pressure is the pascal (Pa), which is equivalent to a force of 1 newton (N) per square metre. That is, $1Pa = 1N/m^2$.

It turns out that a column of air one square centimetre in cross section, measured from sea level to the top of the Earth's atmosphere, has a mass of about 1.03kg and a weight of 10.1325N. This corresponds to a pressure of $101{,}132N/m^2$, or 101,325Pa (= 101.325kPa = 1013.25hPa, since 1hPa = 100Pa). So the standard atmosphere is defined as 101,325Pa or 1013.25hPa.

The actual barometric pressure at any particular location depends upon its elevation or altitude with respect to mean sea level (MSL), because the higher the elevation, the lower the weight of air directly above you and the lower the pressure.

For low altitudes, pressure can be estimated as falling by about 10hPa for every 100m rise above MSL. For higher altitudes, the pressure at any elevation or altitude can be found by a standard expression known as the 'Barometric Formula'.

The first barometers (invented in 1643 by Italian physicist Evangelista Torricelli) measured atmospheric pressure with a column of mercury in a vertical glass tube, and as a result, they were calibrated in terms of the height of the mercury column, measured in either millimetres or inches. So that's where the 'mmHg' and 'inHg' units of pressure came from.

In fact, 'inHg' is still used in the United States, Canada and Colombia. For the record, one standard atmosphere of 1013.25hPa is equivalent to 760mmHg or 29.92inHg.

So where do the bar and the millibar units fit in? Well, the bar was a unit of weight used in the metric system before about 1800. Then around 1890, it was used as a unit of atmospheric pressure by Norwegian physicist and pioneering meteorologist Vilhelm Bjerknes. Since then, it has been used sporadically as a unit of atmospheric pressure, although nowadays it is frowned upon and not regarded as part of the SI system of metric units.

For the record, 1 bar is regarded as equal to 100kPa or 1000hPa and 1mbar equal to 1hPa or 100Pa. Thus, a standard atmosphere corresponds to 1013.25mbar or 1.01325bar. For further pressure information, just visit: **https://en.wikipedia.org/wiki/Atmospheric_pressure**

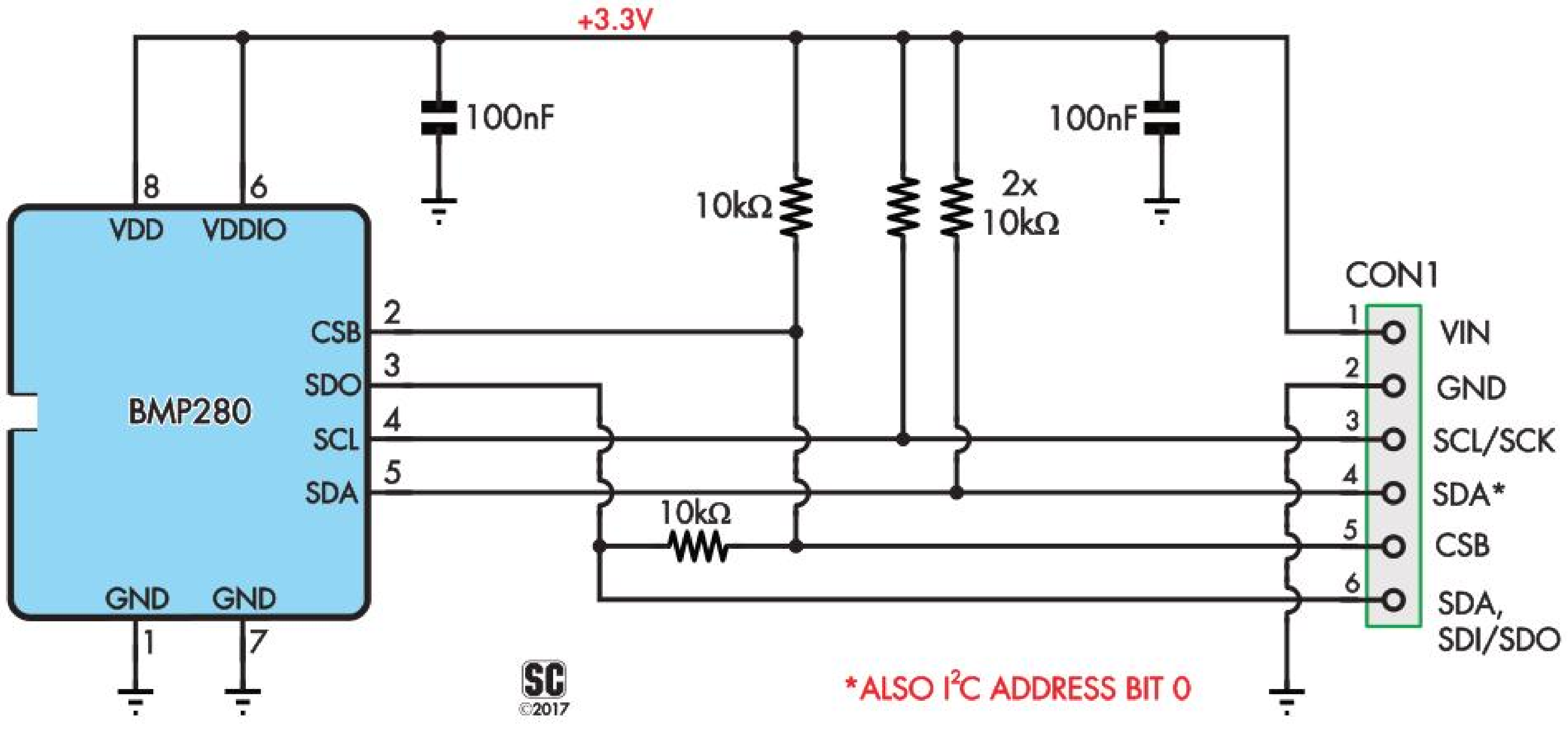
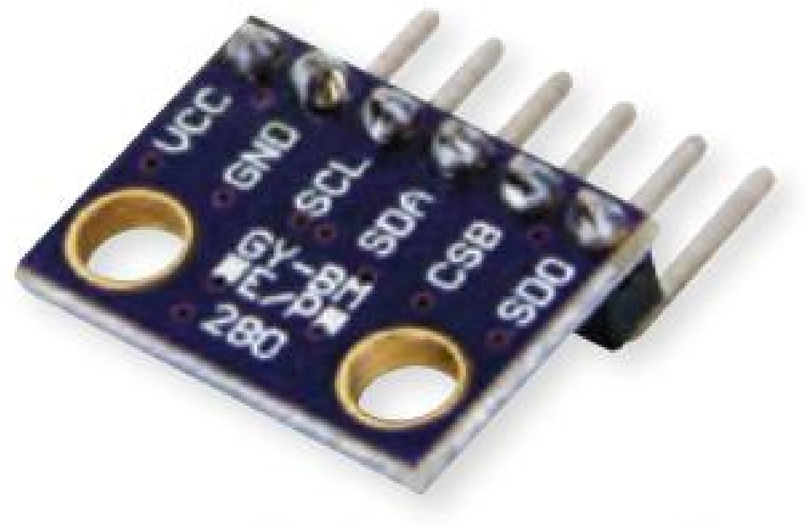


Fig.8: (left) complete circuit diagram for the GY-BM module. Compared to the GY-68's circuit shown in Fig.2, this device is quite a bit simpler in design, removing the need for an external regulator.



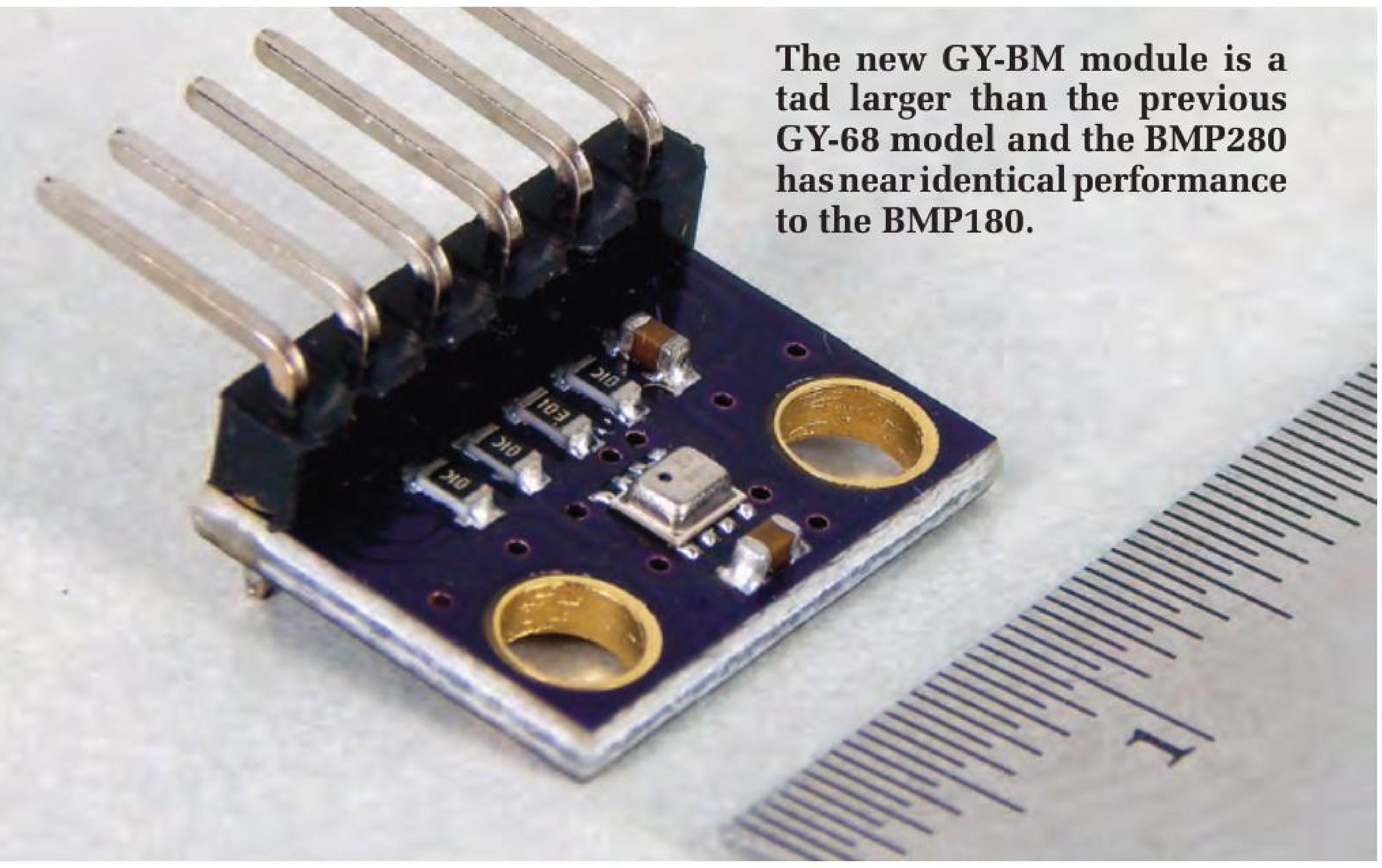
The GY-BM module shown above, close to actual size.

6 of CON1, the SDO line to pin 4 of CON1, the SCK line to pin 3 of CON1 and finally the CSB (Chip Select-bar) line to pin 5 of CON1.

The GY-BM module should be just as easy to use as the GY-68 module. Just make sure that you connect its supply input V_{IN} (CON1 pin 1) to +3.3V, not the +5V supply used for the GY-68 module. Otherwise the BMP280 chip may be irrevocably damaged.

This module is typically even cheaper than the Elecrow GY-68 and is available from the same three vendors (and others): Banggood, AliExpress and eBay. Do note that it is often called the 'GY-BMP280-3.3'.

For both modules it pays to shop around, (keep an eye on delivery costs).



The new GY-BM module is a tad larger than the previous GY-68 model and the BMP280 has near identical performance to the BMP180.

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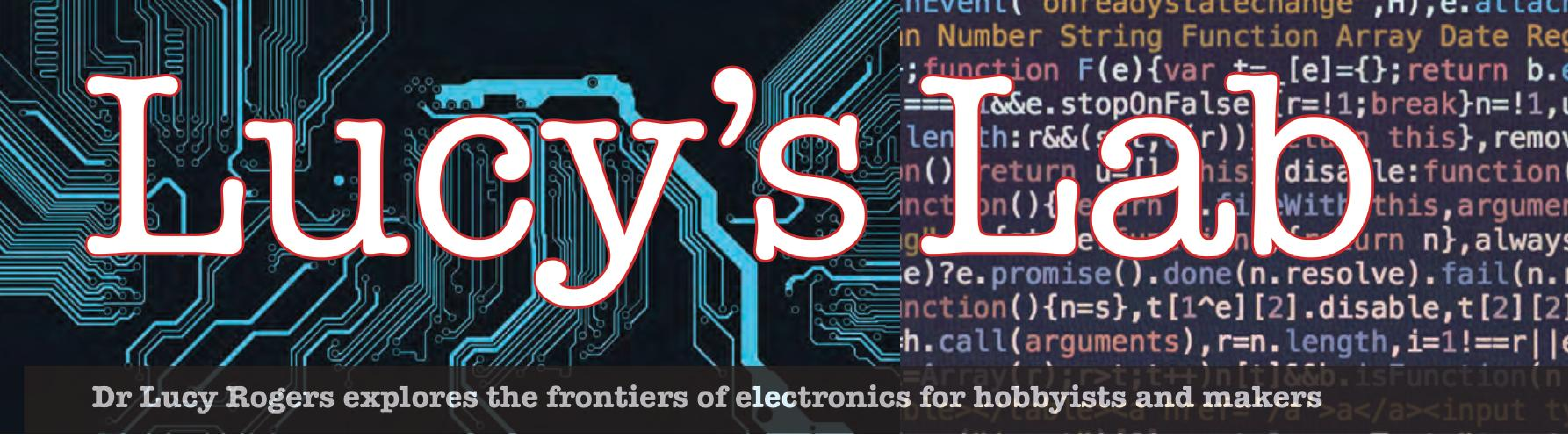


Lucy's Lab

Dr Lucy Rogers explores the frontiers of electronics for hobbyists and makers

Faraday's best field

What do you call 2,000 geeks, makers, crafters, hackers and artists in a field? EMF camp! Electromagnetic Field (EMF) is a non-profit UK camping festival held every two years in the UK.

But it's not just held in any old field. It's an Internet-connected and power-supplied field. I have recently returned from the camp – and the first thing I noticed when I arrived was the orange portable loos that were in every camping area. They were not actual loos, and definitely not Portaloos. These cubicles of delight held all the secret power and Internet supplies.

The 'loos' meant that the hundreds of artistic/geeky/fun creations could be charged and powered and broadcast to, or receive instructions from, anyone around the world. And with the number of inquisitive minds and people interested in making things on site, whichever corner you turned, something new and exciting (or just plain strange) was always on show.

Matt Taylor **@matttaylr** posted some excellent drone footage of the camp on the closing night – including 'all the fire and lasers'. (There was a lot of fire and lasers! – **https://t.co/vtDry6kMKq** – more images on the event can be found at: **http://bit.ly/EPE-EMF2018**).

Busy busy busy

There was also a packed timetable of talks, performances, and workshops. These covered everything from blacksmithing, biometrics and chiptunes to computer security, high-altitude ballooning, lockpicking, origami, democracy, online privacy, and *– of course –* knitting. There was also an electronic 'badge' (**http://bit.ly/EPE-EMF2018-badge**) for every delegate. Each badge was a fully functioning fully hackable python-powered mobile phone. The camp became, for a while, the smallest fully licenced mobile phone operator with a GSM network. Many experts (geeks) at the camp wrote apps that they made available in the badge app store – including, apparently, a dating app.

There was also a lot of good beer! In the evenings, I was attracted to the Nullsector – a container-style 'night club' with lasers, fire, music, things, smoke, more things, and a shopping village where you could buy electronic kits and LED eyelashes and other cool goodies. Did I mention you could control the fire using arcade style buttons? Oh yes. And play arcade games? Including, a 3D *Snake* game on a 1m^3 8×8×8 RGB LED cube built by Lorraine Underwood – find out why this included drilling 512 ping pong balls at: **http://bit.ly/EPE-LEDcube**

The Nullsector was the creation of Charles Yarnold and Benjamin Blundell – Benjamin's write up of how they did it is here: **http://bit.ly/EPE-EMF2018-cybar**

Knitting the night sky

Two years ago, at my first EMF camp, I gave a talk on robot dinosaurs (**http://bit.ly/EPE-EMF2018-dinos**). Back then, in what feels like a lifetime ago, I knew ten people at the camp. And seven of those I only knew via Twitter. This year, the whole camp was full of friends – virtual and real. It was excellent to put some faces to avatars, to see their creations, to hear their talks and stories and generally chat. It was also great to meet new people – and see things I never would have dreamed of making myself. For example, Australian software engineer Sarah Spencer has spent years hacking and programming a 1980s domestic knitting machine for fun. She can now make it knit any image she sends it. And so she made a very large (it's probably over 3m wide and 5m long) star map. The location of the stars was determined by date and time: 6pm Friday, 31 August UK time, which was when EMF opened and the tapestry was unveiled for the first time. It's definitely a stellar feat – there are a few blogs out there about it: **http://bit.ly/EPE-EMF2018-PiKnit** and **http://bit.ly/EPE-EMF2018-PiKnit-starmap**

Fail better

Located between the bar and the First Aid tent was a slackline – a two-inch wide length of webbing, suspended about two feet above the ground. At the end was a tripod where you could attach your phone. You could film yourself trying to balance on the slackline and upload it for the world to see. The point being everyone smiles when they fall off – having fun by failing. This was set up by John Thurmond, who then gave a talk about being a 'Failure Enthusiast': **http://bit.ly/EPE-EMF2018-fail**

Robert Karpinski gave an excellent talk, 'Life after Robot Wars' – **http://bit.ly/EPE-EMF2018-Karpinski** – although he had no real advice for Life after Robot Wars for ex judges, other than more judging at events like Hebocon!

So, I went and judged the EMF mini -Hebocon competition to find the best worst robot (yes, 'best worst' is a thing). Robots are pitted against each other in a sumo wrestling type challenge – the first to fall off the arena (table) loses. However, the robots have to be, 'simple and made of tat'. One was a motor attached to a battery and a plastic fork. Another was a tin of baked beans with some movement device. Some robots just committed suicide and drove backwards off the table. Others won by getting themselves wedged under others. The event was gloriously compered by Tom Scott, who made sure the participants and audience had a fun time. My role was to decide which bot had won if there was no clear winner. This was mainly done on distance travelled, aggressiveness... and a bit of gut feel.

The whole three days of the EMF event were superbly run and organised by the Founders Jonty Wareing and Russ Garrett and a huge team of dedicated volunteers. I have every respect for them all – it can't be easy!

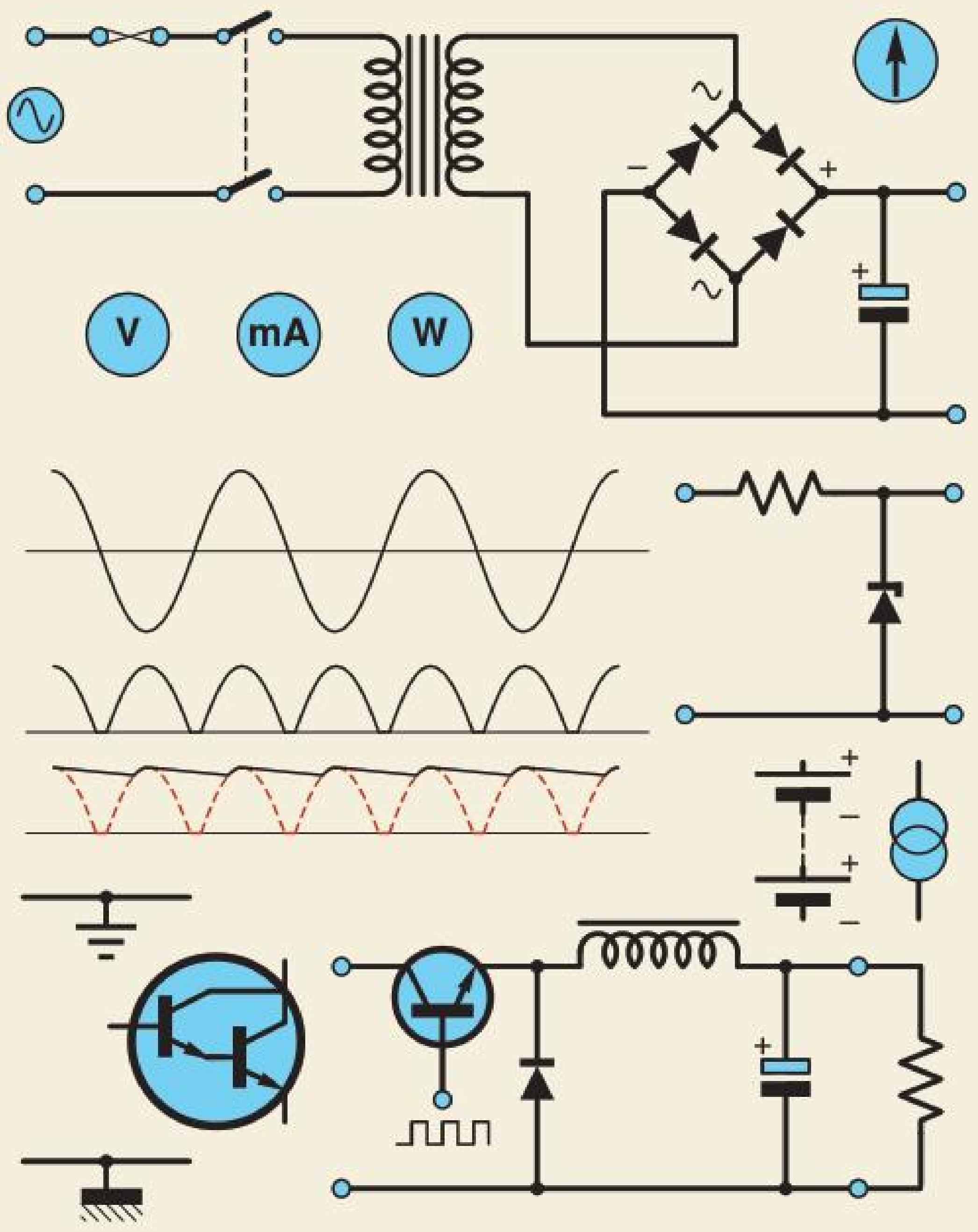
My two favourite quotes of the weekend, "There are many different types of weird here, and every one of them is acknowledged and accepted." And, "Finally, I have found my peeps".

(*Faraday? – in 1849 he invented the term 'field' as we now use it in physics.*)

Teach-In 2019

Powering Electronics

Part 1: Power for your project



by Mike Tooley

Your project is finished and ready to go, but the job isn't done until you've found an appropriate source of power. This could be as simple as choosing a suitably rated mains adapter or as complex as designing a switched-mode power supply with multiple outputs and battery backup. Our latest series – *Teach-In 2019* – is here to help, and will provide you with insight into all aspects of powering your electronic projects and designs.

In *Part 1*, we start the series this month by introducing some key concepts and basic theory. For good measure, our *Teach-In Practical Project* takes the form of a variable load with built-in metering. This handy device will allow you to test a wide range of low-voltage DC power supplies at load currents of up to 5A.

This month

The Teach-In 2019 series pays homage to the unsung hero of most electronic circuits; the power supply. All too often it is taken for granted and is simply not accorded the attention that it really deserves. We just assume that it's there and doing its job properly. However, the correct operation of a power supply is crucial to all electronic circuits. Furthermore, failure of a power supply (which can often be put down to poor design) can be catastrophic for the circuit it is powering and dangerous to the user, so there's also a need to consider its suitability for the job in hand.

The essential starting point is to draw up a detailed specification for your project in terms of its power requirements. This will allow you to consider a range of different solutions that can later be refined and optimised. Let's take a simple example. Your latest project is an Arduino-based weather station that uses remote sensors and outputs its data by means of a wireless interface. The weather station is to operate continuously from a remote location and should only require minimal occasional maintenance.

The Arduino and interface board requires a notional supply of 7V at less than 0.5A (a fairly constant load of around 3.5W). This need could easily be satisfied by an off-the-shelf mains power unit (there are plenty to choose from). However, since the unit is inaccessible and there's a chance of power failure, there's a need for a battery backup system. This then raises the question of what type of battery should be used and how it can be maintained in a fit state to supply the weather station when the power fails. There's also a need for an automatic changeover system incorporating a power failure signal that indicates the current state of the system power. This all needs quite a bit of thought.

Another example might be a power supply for use with a high-quality

14.69 V
1.18 A
voltage
current
17.3 W
14 Wh
power
energy
INDUSTRIAL
by DURACELL
Professional Alkaline Battery
ALKALINE
HW-632

Fig.1.1. Just a few of many solutions to the problem of providing power for your projects.

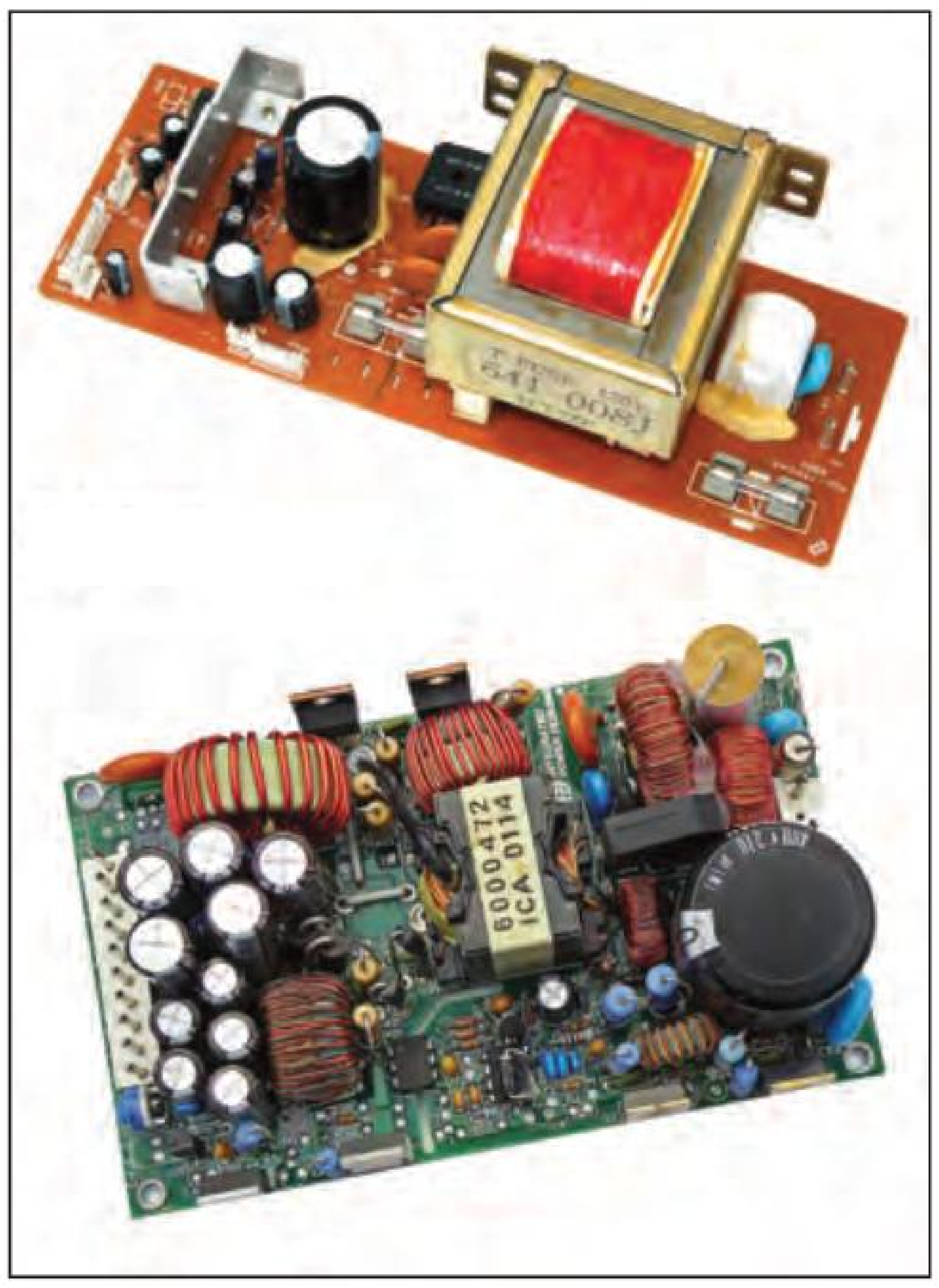


Fig.1.2. Above, a typical linear power supply compared with (below) a switched-mode power supply (SMPS). Both supplies produce multiple outputs and are similarly rated, but are suited for quite different applications.

audio amplifier. This might require 35 to 40V at 4A and could easily be derived from a simple mains transformer and bridge-rectifier arrangement. However, inadequate regulation of the supply voltage will result in significant distortion at high volume levels as the output voltage falls under load. The large amount of residual mains hum that will be present will result in a noticeable output hum at low volume levels. Some means of holding the output voltage constant and at a steady level will be essential. Also, there's a need to protect the power supply from a catastrophic failure occurring within the amplifier (such as a short-circuit output transistor) and some form of fast-acting automatic current limiting will be essential.

Each part of our *Teach-In 2019* series will end with a simple but useful constructional project. Not only will these circuits help you to put into practice the concepts that we will be introducing, but also they will also act as building blocks that can be easily adapted for your own use.

Characteristics and key specifications for power supplies

- **Protection** – What might happen if the incoming supply fails? What might happen if there is a fault in the load connected to the power supply? Can the power supply withstand a short-circuit at its output (either permanent or temporary)?
- **Continuous load and efficiency** – What is the continuous load on the power supply? What power will be dissipated within the supply and what arrangement must be in place to cope with temperature increase? Is efficiency an important consideration and, if so, what should the minimum value of efficiency be?
- **Peak load** – If the load isn't continuous, what is the peak load and how much greater is it than the residual load? Can peak current demands be predicted and how long do they last?
- **Duty cycle** – If the load is not continuous (ie, it is repetitive), what is its duty cycle?
- **Hum and noise** – How much ripple and noise can be tolerated? What are the limits on conducted and radiated noise from the power supply and its associated wiring?
- **Reliability** – For how many hours should the equipment operate (on average) before a failure occurs? What is the minimum required value of mean time to failure (MTTF)?
- **Criticality** – What will happen if the power fails? What is the minimum time for which the output should be maintained? Is there a need for a standby power source? Do you need to incorporate power condition signals?
- **Maintainability** – How easy will it be to change/replace the power supply? How easy will it be to repair the power supply at board/component level and will this be an economic solution?
- **Environment** – Under what environmental conditions will the power supply operate? Do you need to consider factors such as temperature, humidity, vibration, radiation and electromagnetic compatibility/susceptibility?

Power supply types and specifications

At first sight, it may appear that there is little scope for variation in the design of such a mundane piece of equipment as a power supply; however, if you consider the widely differing supply requirements of today's electronic circuits, you will quickly appreciate the need for a variety of different supplies matched to the demands of the circuits that they support. A quick look at what's available in the form of 'off-the-shelf' solutions includes a bewildering selection of mains adapters (raw DC voltage supplies), regulated (constant-voltage or constant-current) supplies, high-current supplies, high-voltage supplies, power supplies with variable outputs, isolated supplies and uninterruptible supplies.

We will be meeting these circuits in detail in later parts, but for now we will focus on the characteristics and key specifications for power supplies used in the vast majority of electronic applications. When considering a solution, you should, at the very least, consider several of the factors listed above.

Specifications

Having introduced some of the features that might (or might not) apply in a particular application, it's worth introducing some of the specifications and terminology used. Of course, not all of these specifications will be important in a particular application, but it's worth being familiar with the terminology before we delve into practical circuitry – remember, what's vitally important in one application might be completely irrelevant in another!

The specification of a power supply usually involves such obvious parameters as input and output voltage, and maximum load current. Specifications that you might be less familiar with include the following.

Efficiency

Ideally, all the power drawn from an incoming power source (such as an AC mains supply) would be usefully delivered to the load connected to the output of the power supply. In practice, some power will be lost within the power supply itself. For most purposes we can define efficiency as:

$$\text{Efficiency} = \frac{\text{DC power output}}{\text{AC power input}} \times 100\%$$

It's worth taking a simple example. A small AC mains adapter produces a DC output of 6V at 1.5A for an input of 220V AC at 80mA (0.08A). Since power is the product of current and voltage (P = I×V) the DC output power will be 9W while the input power (using the RMS values quoted) will be 17.6W. Hence the efficiency can be determined from:

$$\text{Efficiency} = \frac{9}{17.6} \times 100\% = 51\%$$

It's worth noting that, in this example a power of 8.6W will be dissipated within the power supply and this will inevitably appear as heat. With all that wasted energy that little black box is going to get warm!

Efficiency is usually specified for maximum rated power. Typical values of efficiency vary from around 50% for linear regulated power supplies to often more than 85% for equivalent switched-mode types. We will return to this important topic later in this series.

Load regulation

Load regulation provides a measure of how well the supply maintains its rated output voltage when on load. It is defined as follows:

$$\text{Load regulation} = \frac{V_{\text{out, off-load}} - V_{\text{out, on-load}}}{V_{\text{out, off-load}}} \times 100\%$$

Once again, it's worth putting this into context. The power supply that we met earlier produces an output voltage of 6V when supplying a current of 1.5A; but without the load connected the output voltage rises to 7.5V (but with the same AC mains input). We can determine the load regulation from:

$$\text{Load regulation} = \frac{7.5 - 6.0}{7.5} \times 100\% = 20\%$$

This value of load regulation is not unusual for low-cost AC mains adapters, but it would be unacceptable for many applications (where a regulation of better than 5% will often be required).

Load regulation curves

Power supply regulation is often illustrated by means of a graph showing output voltage plotted against output

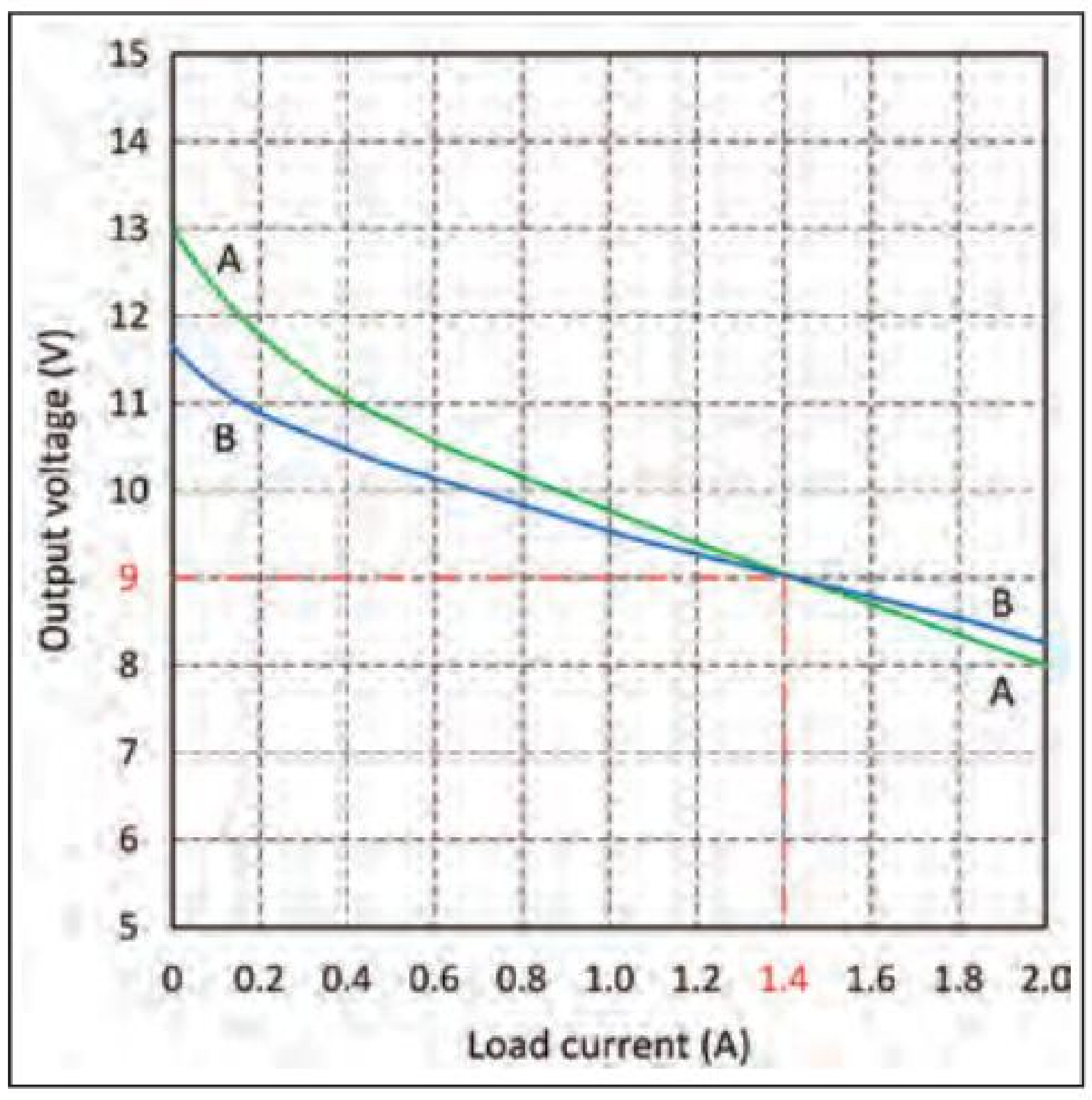


Fig.1.3. Load regulation curves for two AC mains adapters (both rated at 9V, 1.4A).

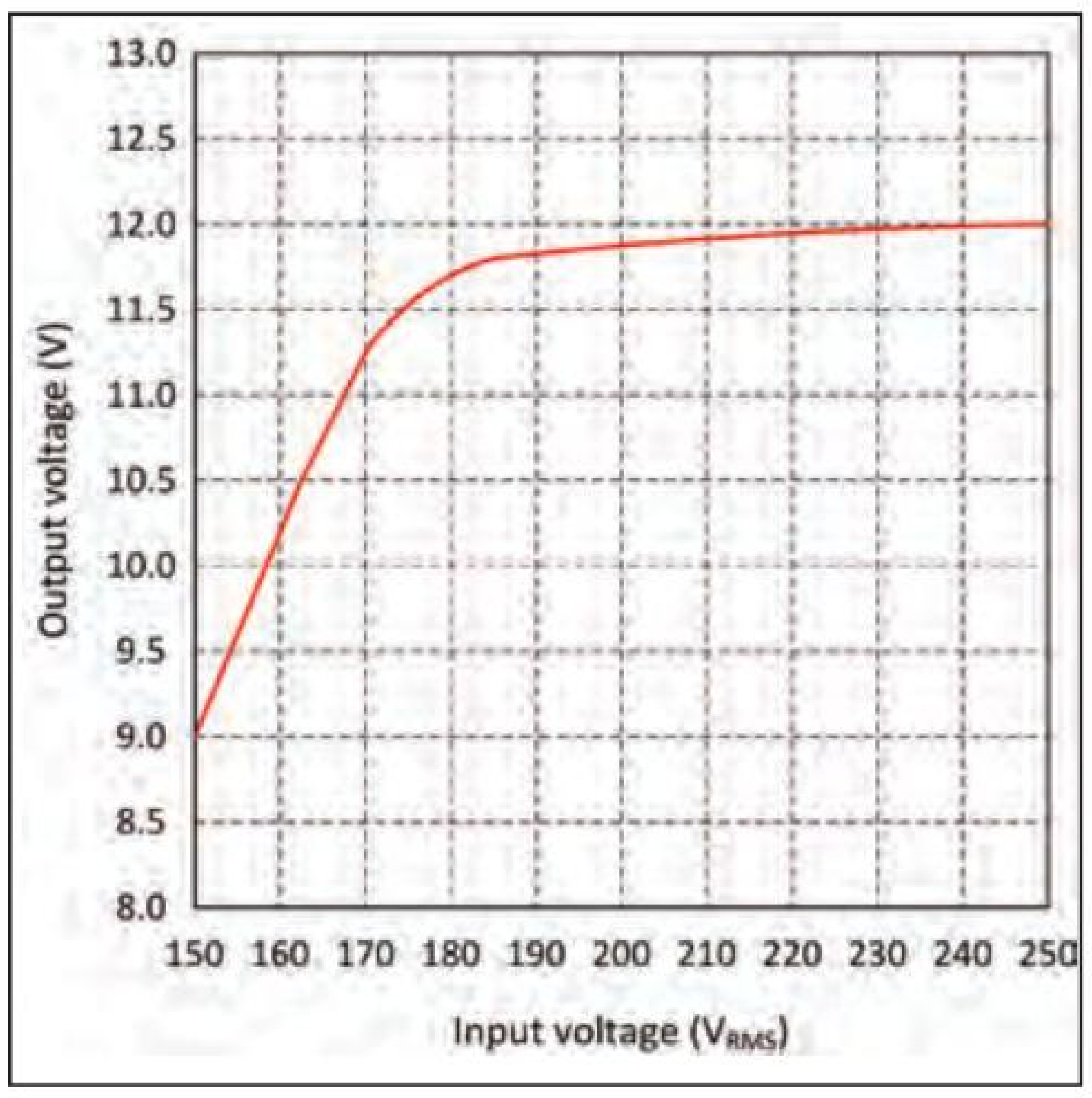


Fig.1.4. Line regulation curve for the author's linear variable bench supply.

current. Fig.1.3 shows regulation curves for two identically rated AC mains adapters (both rated at 9V, 1.4A). Mains adapter A has an off-load output voltage of 13V falling quite rapidly to 8V when delivering 2A. By contrast, mains adapter B has an off-load output voltage of 11.7V falling to 8.3V for a 2A load. Happily, both supplies produce their rated output of 9V for a load current of 1.4A!

The difference in performance of the two mains adapters can be clearly seen in Fig.1.3. Mains adapter A has a regulation of 30% while adapter B exhibits a somewhat better regulation of 23%. Of particular note, however, is that the no-load output voltage of adapter A is 40% greater than its rated output voltage, while that for B is slightly better at 30% greater than the rated output. Unless a voltage regulator is placed after the mains adapter and before the circuit being supplied, this no-load voltage could be a problem.

Line regulation.

Line regulation is defined as the per-unit change in output voltage divided by the corresponding per-unit change in input voltage. The per-unit change in input voltage can be calculated from:

$$\text{Per-unit input change} = \frac{V_{\text{in, high}} - V_{\text{in, low}}}{V_{\text{in, low}}} \times 100\%$$

The per-unit change in output voltage can be calculated from:

$$\text{Per-unit output change} = \frac{V_{\text{out, high}} - V_{\text{out, low}}}{V_{\text{out, low}}} \times 100\%$$

Finally, the line regulation can be determined from:

$$\text{Line regulation} = \frac{\text{Per-unit } V_{\text{input}} \text{ change}}{\text{Per-unti } V_{\text{output}} \text{ change}} \times 100\%$$

Note that, as with load regulation line regulation is normally measured under worst-case full-load conditions.

Let's put this into context with another example. Let's assume that a DC power supply delivering its rated load produces an output of 12.5V when the AC input is 240V and that the output voltage falls to 12.1V when the AC supply falls to 200V. The line regulation would be found from:

$$\text{Line regulation} = \frac{\left(\dfrac{12.5-12.1}{12.1}\right)}{\left(\dfrac{240-200}{200}\right)} \times 100\%$$

$$= \frac{0.033}{0.2} \times 100\% = 16.5\%$$

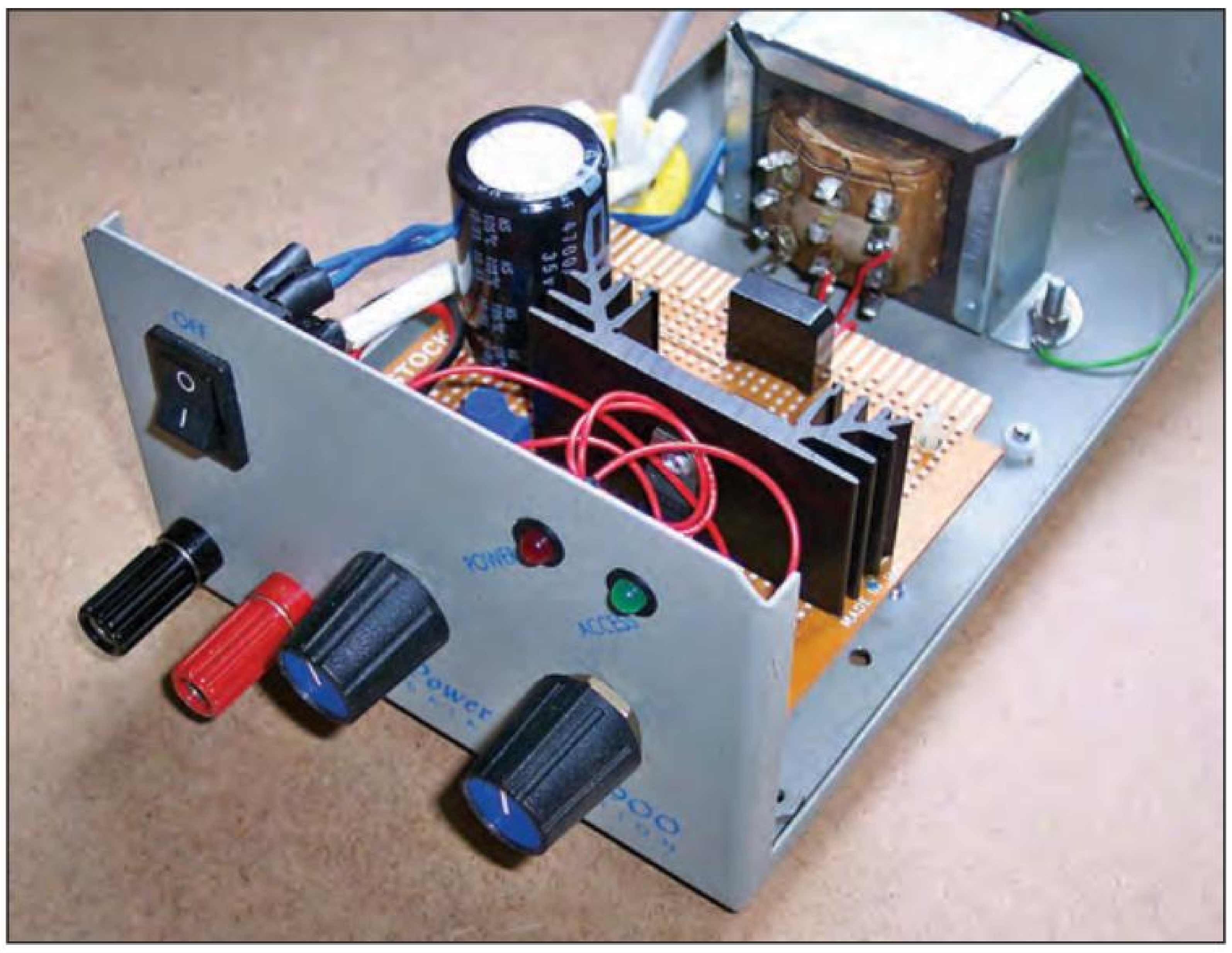


Fig.1.5. The author's home-constructed linear variable bench power supply.

Line regulation curves

Line regulation can also be usefully illustrated by reference to a regulation curve. In this case, output voltage is plotted against input voltage. Fig.1.4 shows the line regulation curve for the author's home-constructed linear variable bench power supply. Note how the regulator drops out below a mains supply voltage of 190V. Above this, the output voltage is maintained reasonably close to the set value (in this case, 12V with a full load of 800mA applied).

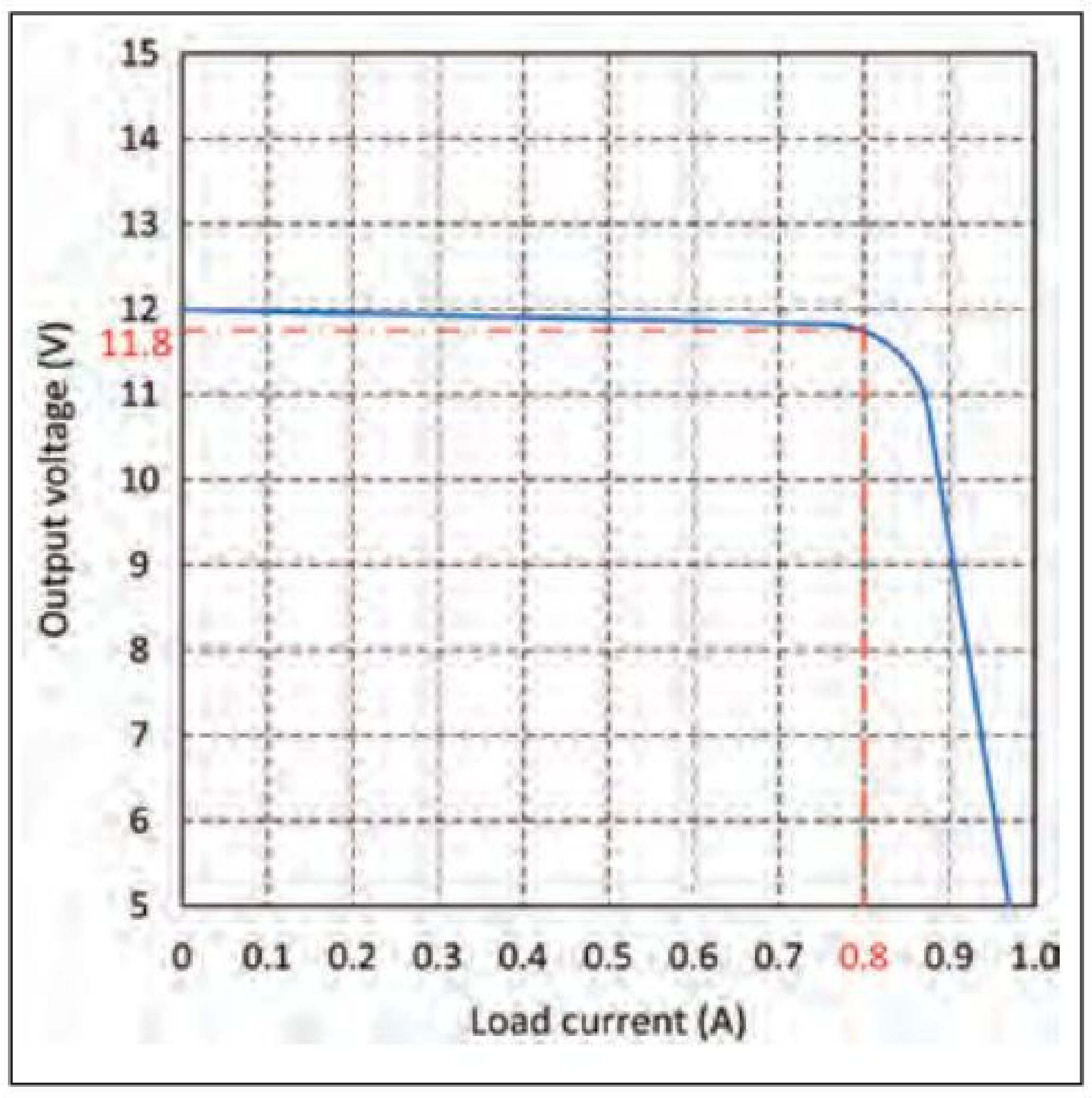


Fig.1.6. Load regulation curves for the author's linear variable bench power supply.

Fig.1.6 shows the corresponding load regulation curve for the author's linear variable bench supply. Note how the over-current limiting circuitry operates when the load current exceeds 0.8A. Thereafter, the output voltage falls very rapidly in order to protect the power supply circuitry.

Output resistance

The output resistance of a power supply is the ratio of the change in DC output voltage to the corresponding change in output current as the load on the power supply is varied. In *Part 3*, we will be looking at this in much greater depth. The output impedance is given by:

$$\text{Output resistance} = \frac{V_{\text{out, off-load}} - V_{\text{out, on-load}}}{I_{\text{out, on-load}}}$$

Once again, this specification is usually quoted when the power supply is delivering its rated output current. Let's look at another example.

As shown in Fig.1.6, the output of the author's linear variable bench supply falls from 12V to 11.8V at full load (0.8A). The output resistance can therefore be calculated from:

$$\text{Output resistance} = \frac{12.0 - 11.8}{0.8} = 0.25\Omega$$

The load regulation of the author's linear variable bench supply can also be found from the load regulation curve:

$$\text{Load regulation} = \frac{12.0 - 11.8}{12.0} = 1.7\%$$

Ripple and noise

Unfortunately, the output of a DC power supply can often be contaminated by the presence of unwanted components such as ripple and noise. These components become superimposed on the DC output and steps must be taken to reduce them to levels that don't have any effect on the circuitry that derives its power from the supply. Note that, when conducted or radiated, noise can also be a problem for other nearby equipment. We will examine

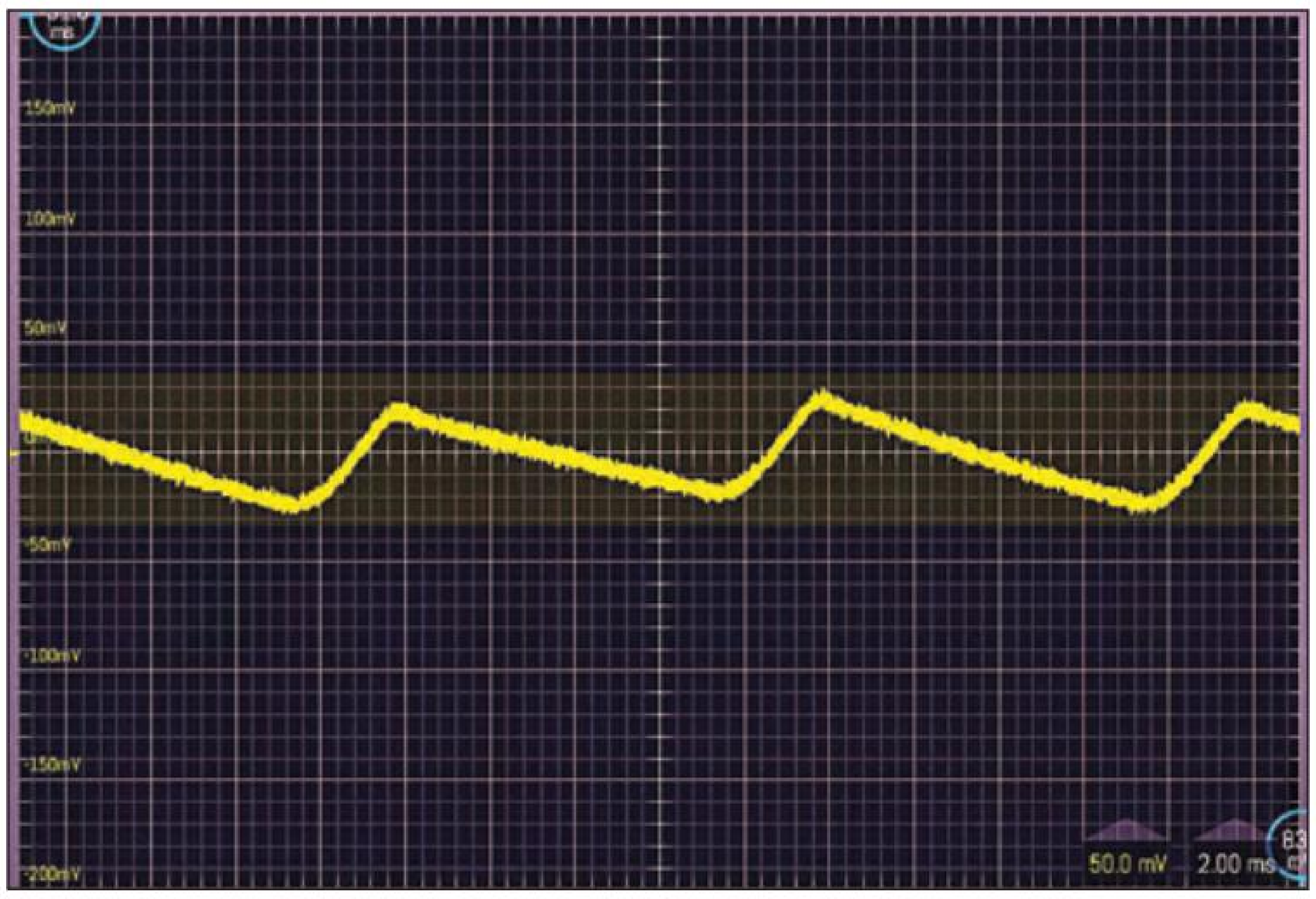


Fig.1.7. Ripple present on the output of a budget linear power supply. The ripple is at 100Hz (twice the mains supply frequency) and has an amplitude of 50mV.

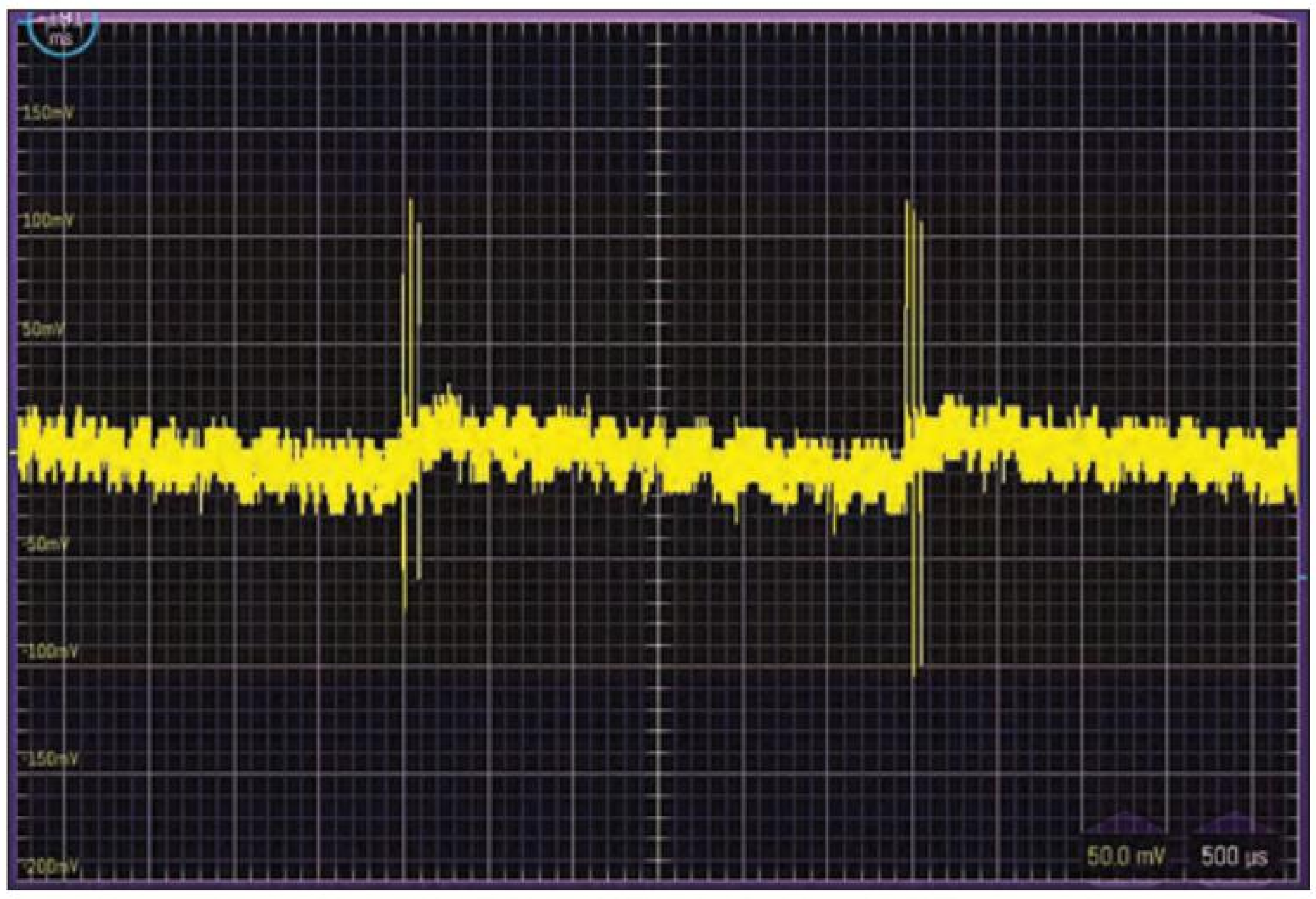


Fig.1.8. Noise and switching transients present on the output of a budget SMPS power adapter. The noise has an amplitude of 40mV and the switching transient has a somewhat worrying peak-peak value of 400mV.

this important problem in much greater detail later in this series but, for now, we will concentrate on the presence of ripple resulting from the use of an AC mains supply. This may be quoted in several ways, including RMS or peak-peak ripple voltage superimposed on the DC output and also by a 'ripple factor', defined as:

$$\text{Ripple factor} = \frac{V_{\text{on-load, RMS ripple}}}{V_{\text{out, on-load}}}$$

A figure is sometimes also quoted for 'ripple rejection'. This is a measure of the ability of a regulator or smoothing circuit to reduce the AC ripple component present. Ripple rejection can be calculated from:

$$\text{Ripple rejection} = 20\log_{10}\left(\frac{V_{\text{on-load, input RMS ripple}}}{V_{\text{on-load, output RMS ripple}}}\right)$$

Project: Variable Test Load

If you are testing power supplies on a regular basis, one of the most useful gadgets to have available is a reliable test load. This will allow you to easily extract current from the supply and monitor the output voltage under different load conditions. Test loads can be purchased as ready-made devices, but they tend to be specialised units and can often be rather expensive (particularly for high power levels). Happily, it is quite easy to construct a variable test load from a handful of low-cost components, as we will now show.

Designed originally for checking 11V to 13.8V supplies, our variable test load (see Fig. 1.9) is ideal for testing low-voltage DC supplies at currents up to 4A. It can also be used, with reduced performance, at voltages from 5V to 20V (maximum) and at currents of 5A (maximum). The dissipation should be limited to around 60W for short periods or 40W for continuous operation. This should be adequate for the majority of low-voltage DC supplies.

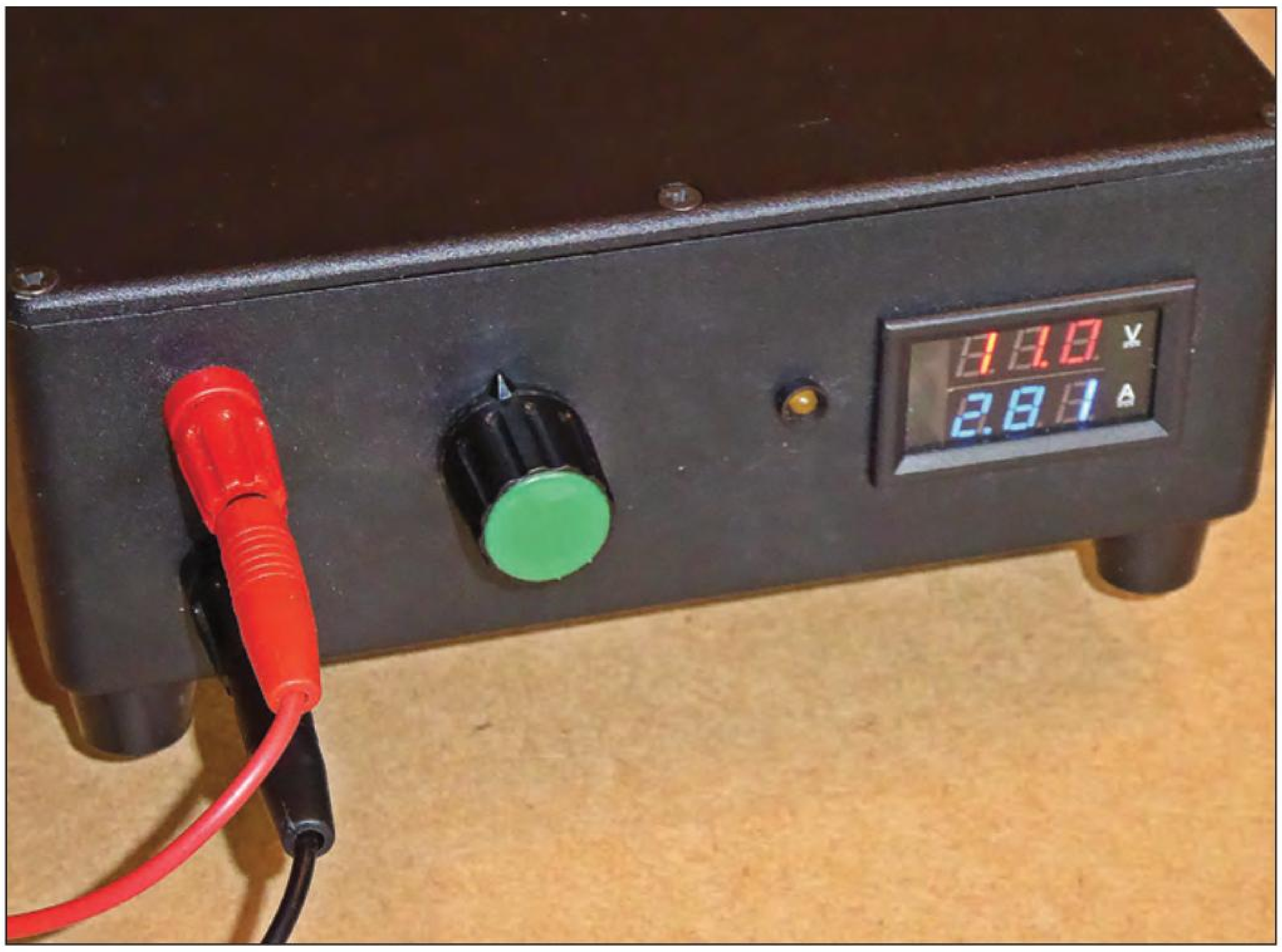


Fig.1.9. A variable test load can be invaluable if you are testing power supplies on a regular basis.

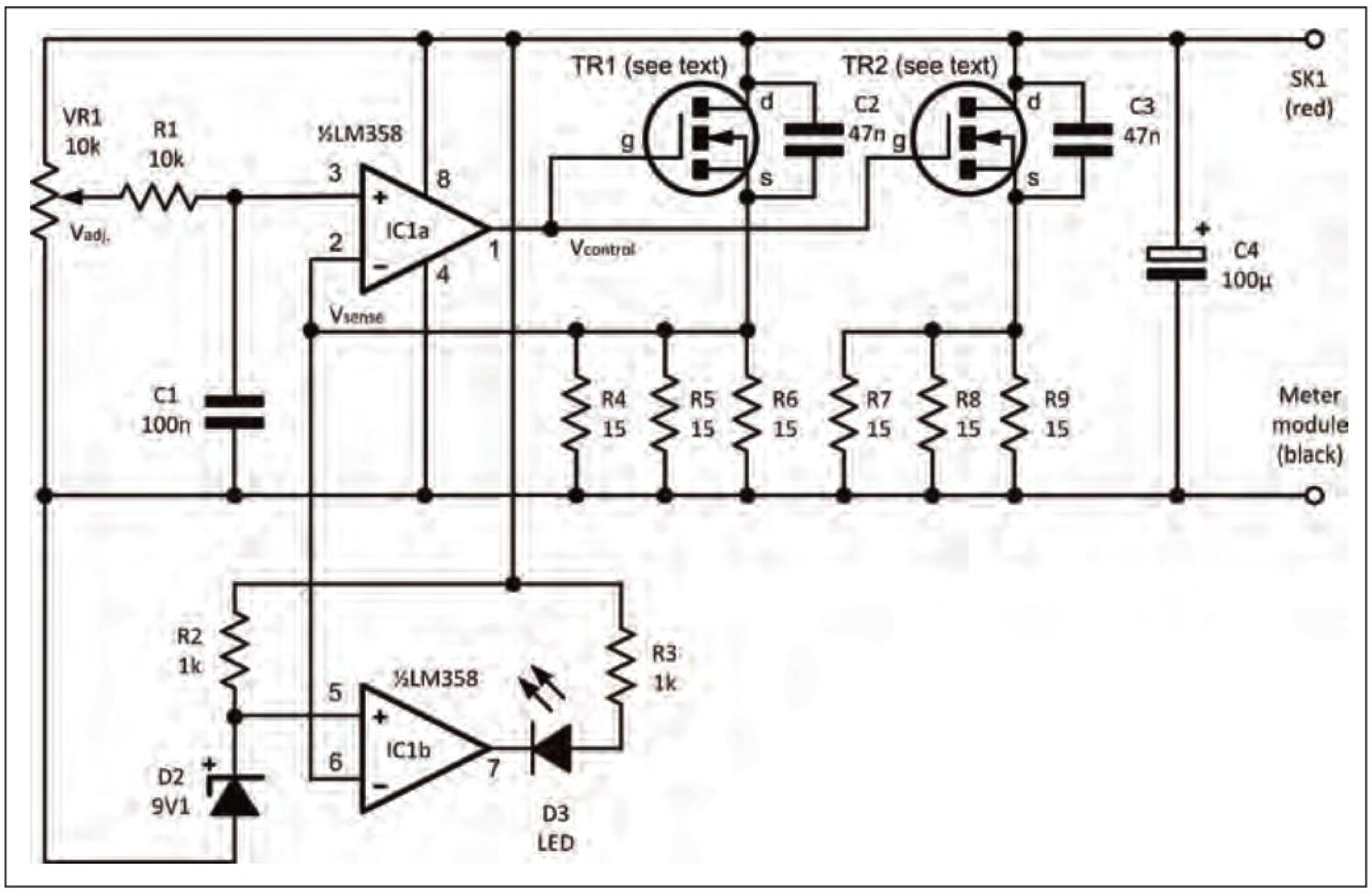


Fig.1.10. Complete circuit of the Teach-In Variable Test Load.

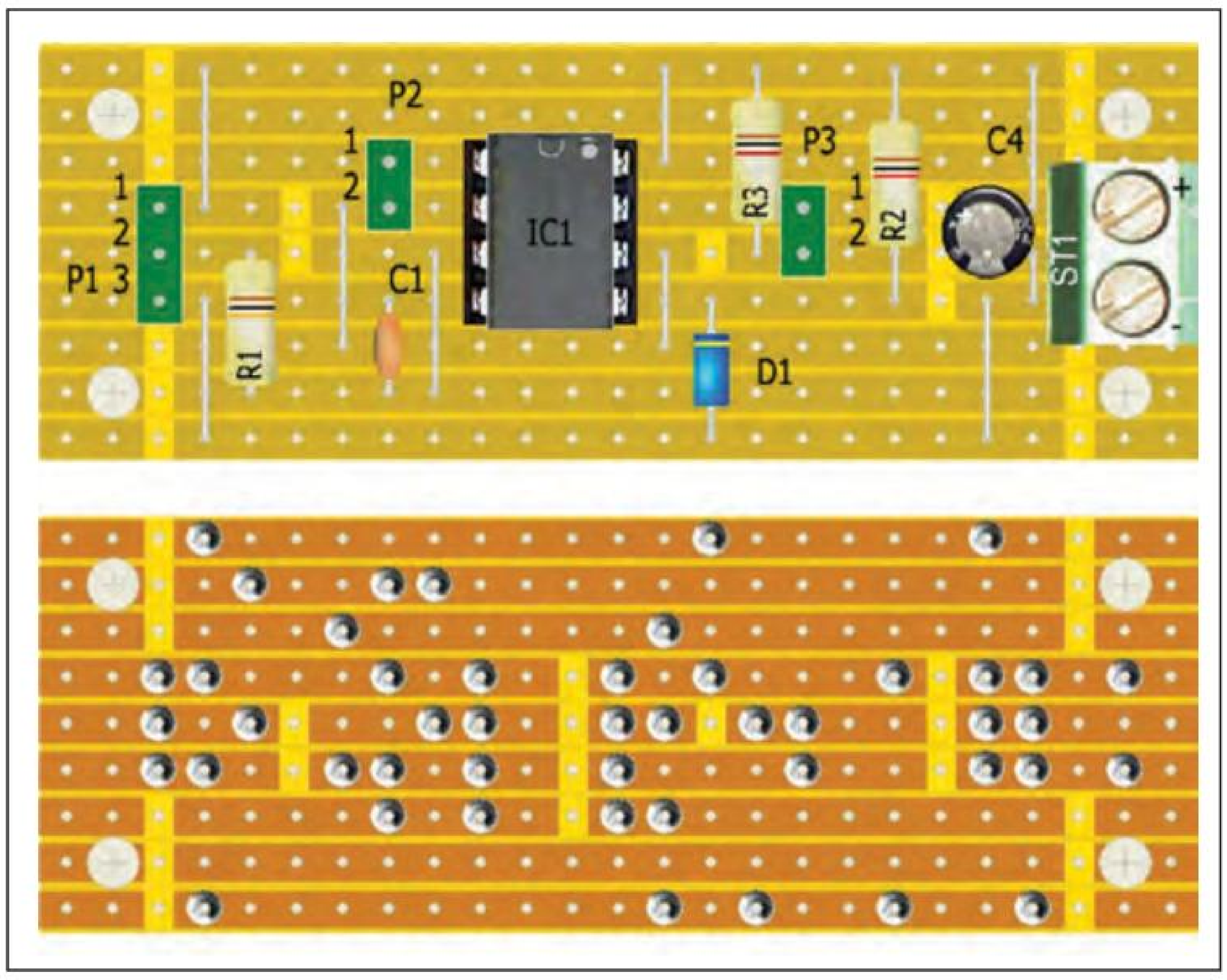

P2
1
2
P3
C4
1
2
P1 3
R1
C1
IC1
R3
1
2
R2
ST1
+
-
D1

Fig.1.11. Stripboard layout of the control board for the Teach-In Variable Test Load – (top) component side, (below) copper side.

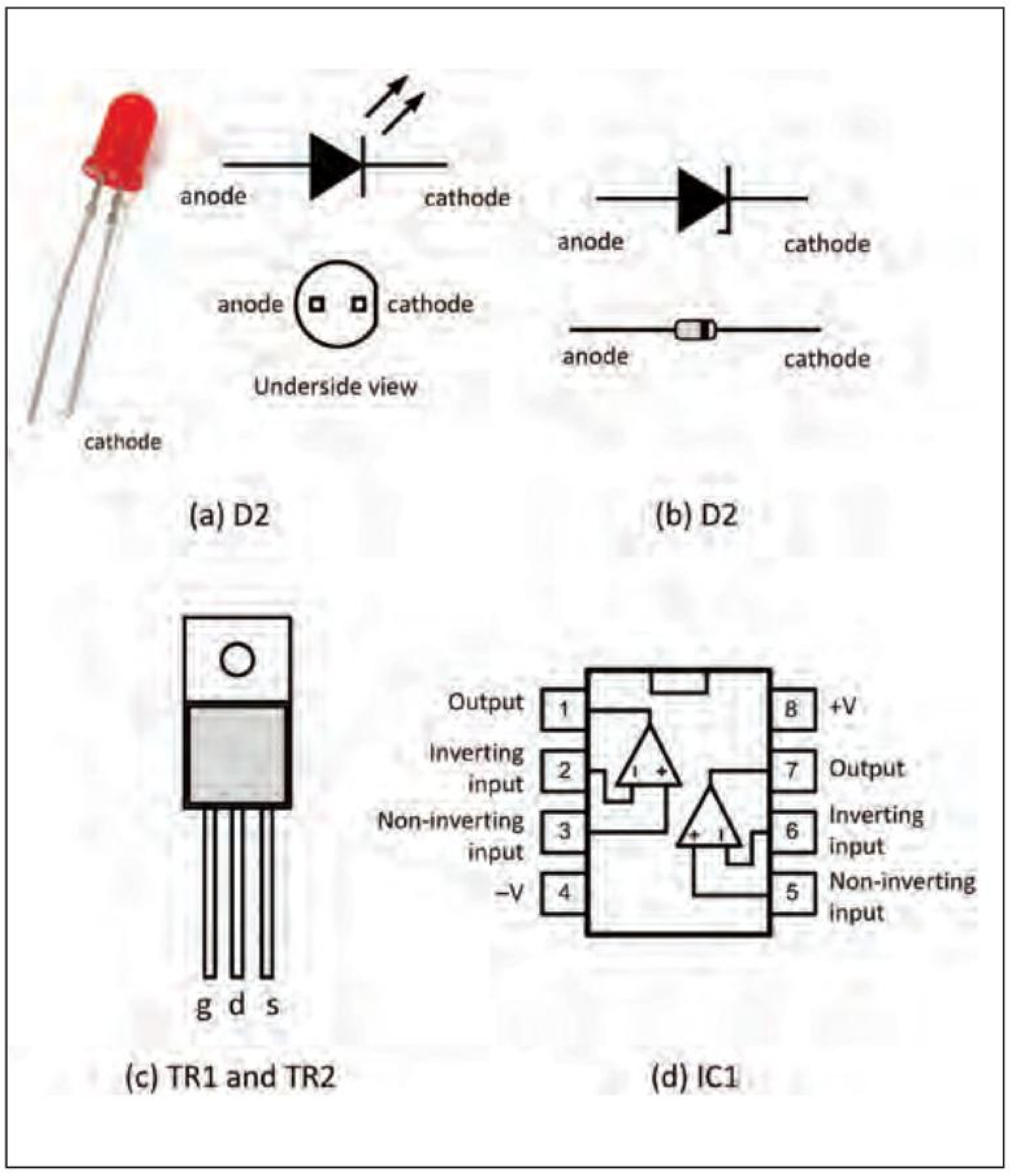
Circuit description

The circuit of our variable test load is shown in Fig.1.10. The dissipated power is shared between two N-channel power MOSFET devices and six high-power aluminium clad resistors. The control device is an LM393 operational amplifier and this also provides an over-current warning that operates when the load current exceeds 3.5A.

The MOSFET devices used in the author's prototype variable test load were RFP30N06LE. These are intended for logic-level switching, but they can also be used as a simple analogue control element by applying a variable DC voltage to the gate, of around 1.5V to 3V. Any similar TO-220 device can be used in this application, provided that it is suitably rated (eg, 15A, 50V).

One half of the LM393 (IC1a) acts as a comparator with its output ($V_{control}$) taken to the gate input of both TR1 and TR2. The voltage developed across one half of the resistive load (V_{sense}) is fed back to the inverting input (pin-2) while the required set value (V_{adj}) is applied to the non-inverting input (pin-3). The two power MOSFET devices are operated as source followers, with three metal-clad high-dissipation resistors connected in each source load (R4 to R6 for TR1, and R7 to R9 for TR2).

The second half of the LM393 (IC1b) is also used as a comparator. The non-inverting input (pin-5) is supplied from a shunt Zener voltage reference (approximately 9V) while the load voltage (V_{sense}) is applied to its inverting input (pin-6). When V_{sense} is less than 9V, the comparator output (pin-7) is high and no current flows in the LED (D3). Conversely, when V_{sense} is greater than 9V (corresponding to a current of 1.8A flowing in the source of TR1) the comparator output (pin-7) is taken low and current flows in the LED. Hence D3 provides an overload warning when it becomes illuminated, at which point the total load current is in excess of 3.5A.


anode
cathode
anode
cathode
Underside view
cathode
anode
cathode
anode
cathode
g d s
Output 1
Inverting input 2
Non-inverting input 3
–V 4
8 +V
7 Output
6 Inverting input
5 Non-inverting input

(a) D2

(b) D2

(c) TR1 and TR2

(d) IC1

Fig.1.12. Semiconductor pin connections for the Teach-In Variable Test Load.

You will need...

- 1 Perforated copper stripboard (9 strips, each with 25 holes)
- 1 Digital voltmeter/ammeter module 100V/10A (eg, DEOK YB27VA-10A from eBay or Amazon)
- 1 Diecast enclosure measuring approximately 188 × 188 × 67mm (eg, Hammond 1590F)
- 1 Heatskink capable of mounting two TO-220 devices rated at better than 4.2°C/W

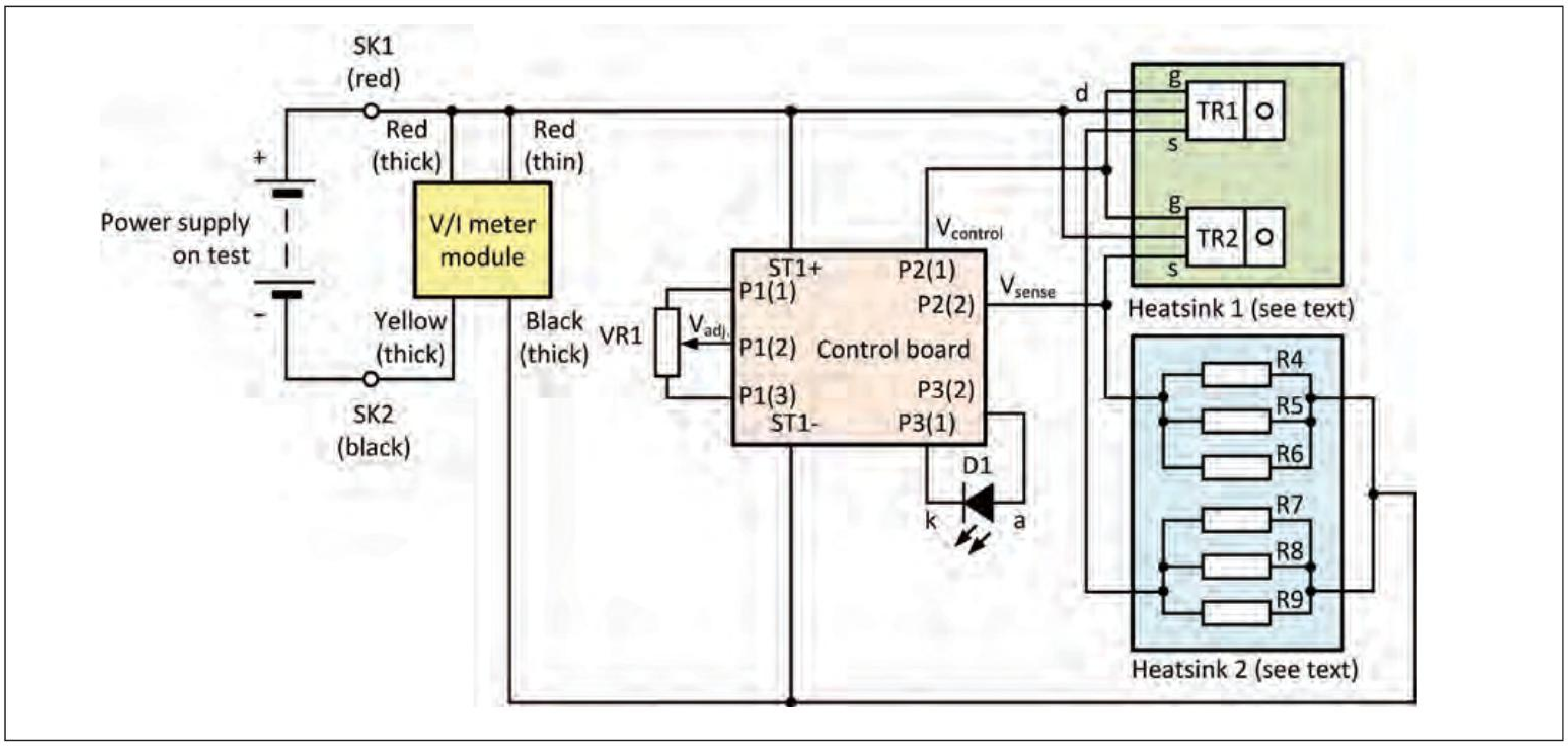

SK1
(red)
Red
(thick)
Red
(thin)
d
g
TR1
s
+
Power supply
on test
-
V/I meter
module
g
TR2
s
V_{control}
ST1+
P1(1)
P2(1)
P2(2)
V_{sense}
Heatsink 1 (see text)
Yellow
(thick)
Black
(thick)
VR1
V_{adj}
P1(2)
Control board
R4
R5
R6
SK2
(black)
P1(3)
ST1-
P3(2)
P3(1)
D1
k
a
R7
R8
R9
Heatsink 2 (see text)

Fig.1.13. Wiring layout of the Teach-In Variable Test Load (note that C2 and C3 are not shown – see text).

1 red 4mm binding post terminal (SK1)
1 black 4mm binding post terminal (SK2)
1 10kΩ resistor (R1)
2 1kΩ resistors (R2, R3)
6 15Ω chassis-mounting metal-clad resistors rated at 25W (R4 to R9)
1 10kΩ linear potentiometer (VR1)
1 100nF capacitor (C1)
2 47nF ceramic disk capacitors (C2 and C3, see text)
1 100µF 35V capacitor (C4)
2 RFP30N06LE N-channel MOSFET transistor (TR1 and TR2, see text)
1 LM393 dual comparator (IC1)
1 red LED
1 9.1V Zener diode (D1)
4 stand-off pillars and mounting screws
2 2-way miniature screw terminal blocks (ST1 and ST2)

Construction

The layout of the control circuit stripboard is shown in Fig.1.11. Note the 21 track breaks and eight links. The pin connections for the semiconductor devices are shown in Fig.1.12. The simplified internal wiring schematic is shown in Fig.1.13. The two small ceramic disk capacitors, C2 and C3 (not shown in Fig.1.13) are wired directly to the source and drain pins of TR1 and TR2. These capacitors are required to prevent the possibility of oscillation due to stray reactance present in the off-board wiring to the heatsink-mounted MOSFET transistors.

Table 1.1 Test voltages for TR1 and TR2 (13.8V, 1A load)

Device	Gate	Source	Drain
TR1	5.1V	2.5V	13.8V
TR2	5.1V	2.5V	13.8V

Table 1.2 Test voltages for IC1

Pin no.	Voltage
1	5.1V
2	2.5V
3	2.5V
4	0V
5	8.6V

The two power transistors must be mounted on a finned heatsink rated at 4.2°C/W, or better. To promote heat conductivity, we avoided the use of insulating washers and instead bolted the tabs of the two MOSFET devices directly to the heatsink, **which means the heatsink must be insulated from the metal enclosure**. Note that the tab of the TO-220 package is directly connected to the drain of each power devices and will therefore be at full positive input potential.

The six metal-clad resistors can be conveniently bolted to the inside of the diecast metal enclosure. If a metal enclosure is not used, a separate heatsink will be required for R4 to R9 and this should also be rated at better than 4.2°C/W. The internal view of the prototype is shown in Fig.1.14.

Testing

Once assembly is complete it is well worth carrying out a careful internal inspection, checking, in particular the off-board wiring. If a voltmeter/ammeter module is not used, the common connection of R4 to R9 can be connected directly to the negative input terminal (bypassing the internal 10A shunt fitted in the meter module). Tables 1.1 and 1.2 provide a set of measured test voltages with the unit adjusted for a load current of 1A from a 13.8V DC source.

Next month

In *Part 2* of *Teach-In 2019* next month, we will be looking at AC to DC conversion, explaining the construction of power transformers and wiring configurations for series and parallel operation. We will also be introducing half- and full-wave rectifier arrangements that can form the basis of building blocks that can be used in a variety of practical DC power supplies. Our *Teach-In Practical Project* will feature the construction of a simple 18V 0.5A raw DC supply for use in conjunction with several of our later *Practical Projects*.

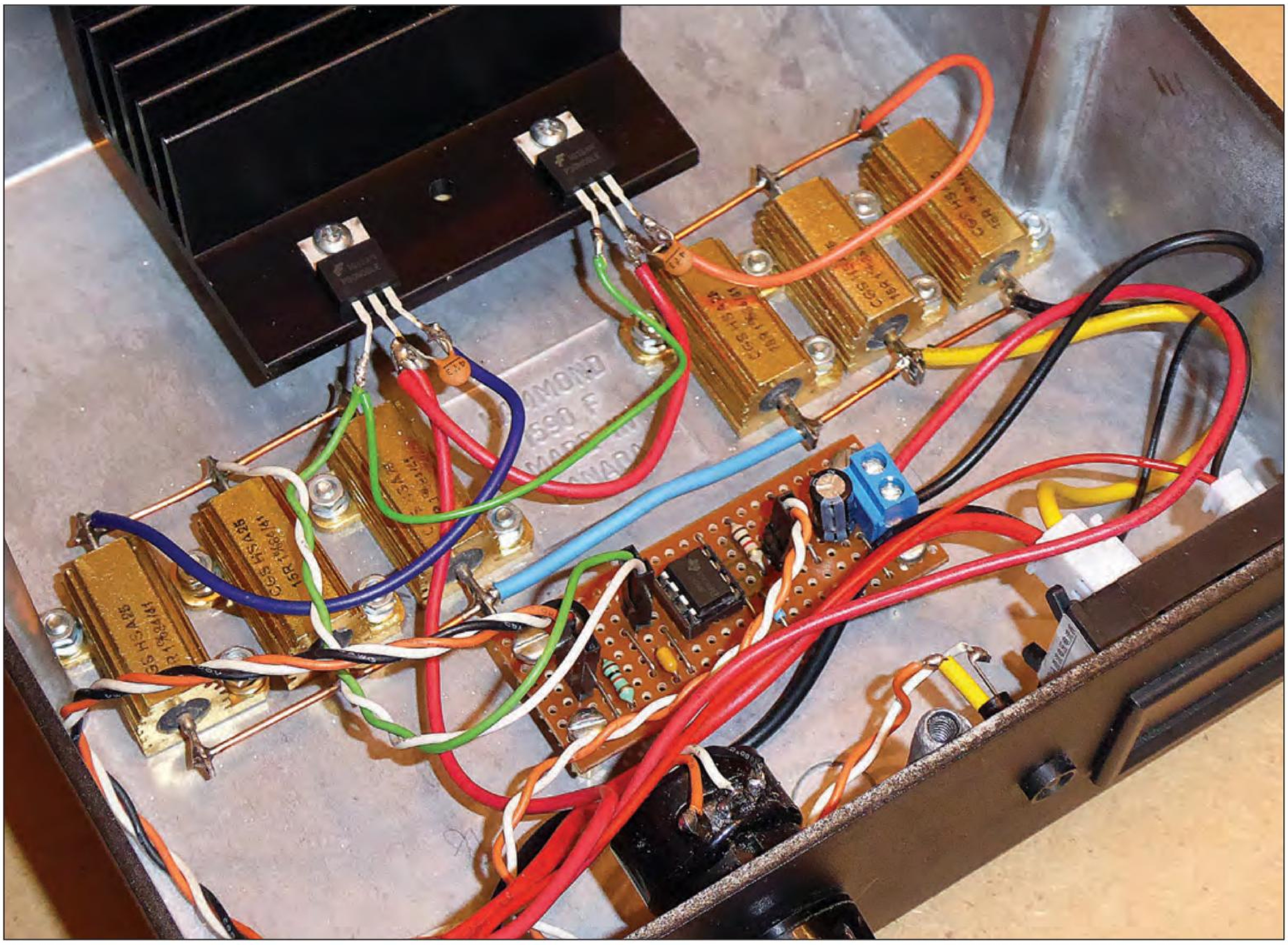


Fig.1.14. Internal view of the Teach-In Variable Test Load.

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICMeter Part 3 – Measuring current

LAST month, as part of the *PICMeter* series, we added a 2.2-inch TFT display and developed some code over an SPI interface to control it. We finished the article with a very basic screen display of raw data from the ADC input, which was measuring an external voltage ranging from 1mV up to 20V. This month, we're moving on to current measurement.

The breadboard is getting rather packed, and it will be hard to add more functionality without ending up with a bowl of metal spaghetti. So, this is the last time we'll be adding much hardware. Next month, we'll revisit the code for the display and provide some customisation options.

Measuring current

If you want to measure something, the first question you should ask is – 'what is it?' Electric current is the flow of electric charge – electrons moving in a wire. There are two varieties of current flow, direct and alternating, commonly known as DC (direct current) or AC (alternating current). Direct current only flows in one direction and is very common in the power supply for most electronic devices. In alternating current systems, the direction of current flow periodically reverses.

The most common AC example is mains power, distributed as 50Hz from the wall socket in your house or office. DC is typically supplied from a battery or some kind of AC/DC converter, which at its most basic might be a single diode. Other DC power supplies include the output from a solar panel, or even a potato – **www.bbc.co.uk/guides/z86syrd**

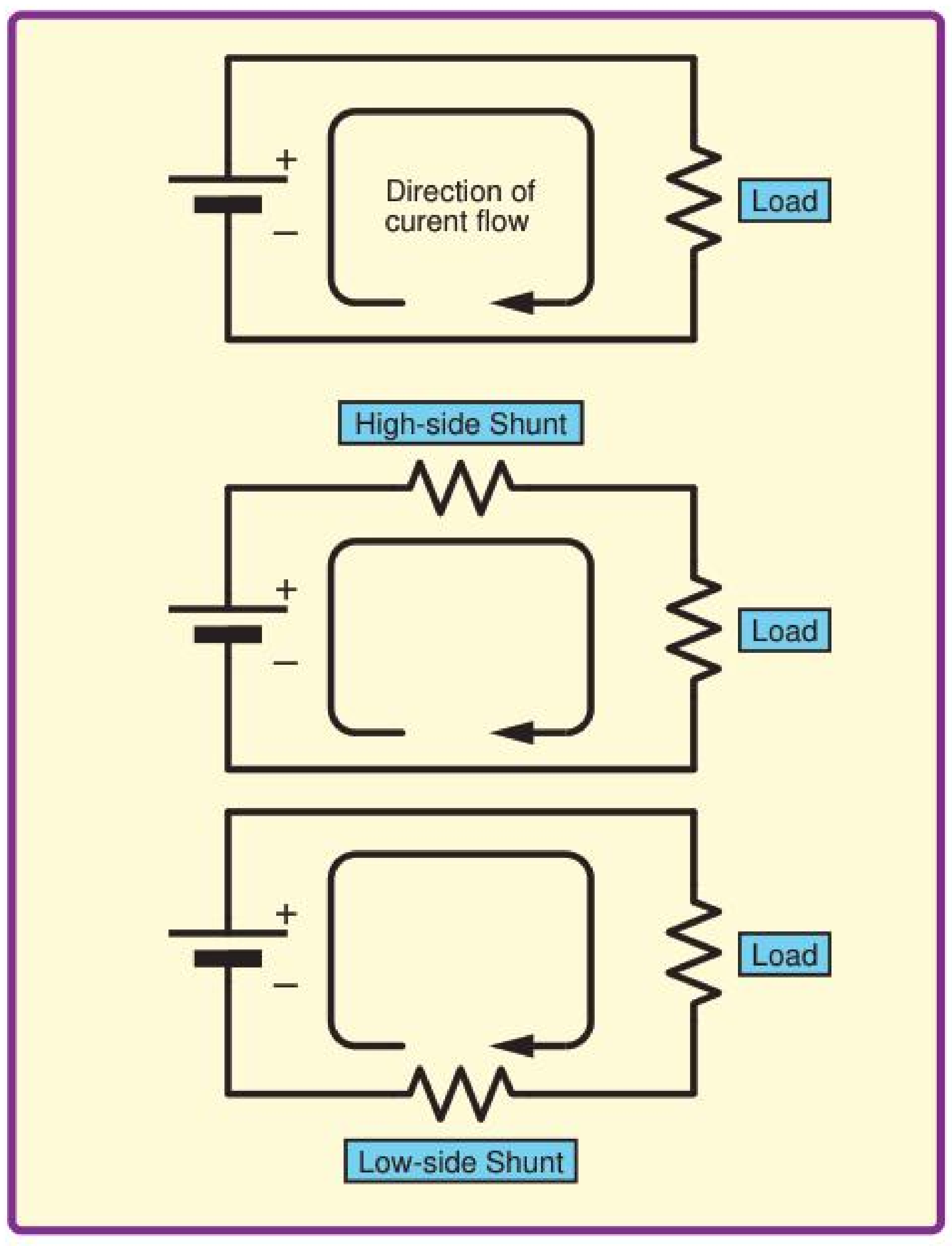


Fig.1. Electric current flow, high-side and low-side current measurement

There are many reasons to measure current flow: to verify the behaviour of a circuit; check how long a battery will last; analyse the current in a device or to calculate heat dissipation, to name just a few examples.

Measuring direct current

Let's start with DC. Often (not always) DC is easier and safer to measure because the voltages involved are much lower than many AC systems. We want to measure DC using a PIC microcontroller, but this presents a problem – most microcontrollers can only measure voltage, using an analogue-to-digital converter (ADC) input. So we need a method to convert the target current into a voltage. Then with some (hopefully simple) mathematics, we can figure out the value of the current.

It is important to note that when we measure voltage, we are measuring it *across* two points in a circuit. This is done *in parallel* with the circuit by touching the positive and negative probes of the voltmeter at two points. However, to measure current, we need to make a measurement through a particular point, which means our sensing is done *in series* with the circuit. This may mean 'breaking' into the conductor carrying the current. When we do this we can either measure on the high side (at the positive terminal of a battery or voltage source) or on the low side (at the negative terminal). Fig.1 shows the typical flow of current from positive to negative. (Incidentally, the direction of the flow of current is an age-old question of electronics. Technically, the electrons flow from negative to positive, but this is not how we illustrate current flow in diagrams, where the flow is shown in the opposite direction (positive to negative).) Fig.1 shows the placement of a high-side and low-side current-measuring circuit, which will be discussed later.

The shunt resistor is one of the simplest methods of measuring current in a circuit. A shunt is a precise, known, low-value resistor in series with a circuit. Usually this is in the order of 0.001Ω to 10Ω.

When a current flows through the circuit, and hence through the shunt, a potential difference will be created across the shunt. Since we know the value of its resistance, and we can measure the voltage dropped across it, we can calculate the value of the current using Ohm's law. Algebraically, we use the well-known relationship: $V = I \times R$, where V is the potential difference (volts) across the shunt (resistance), I is the current through the shunt (amps) and R is the shunt's resistance (ohms). We rearrange this: $I = V/R$ so that now all we need to do is measure a voltage to infer the value of current.

Measuring alternating current

In theory, there is no reason why we can't use the shunt method to measure AC, but there are several problems with this approach. Often, AC is at mains voltage levels, which will fry our PIC. Also, calculating a representative value of current in an AC system is much more mathematically complicated than just using Ohm's law, and last, if the AC frequency is too high then our ADC simply won't be able to keep up with the rate of change of the shunt's alternating voltage. So, we look to other methods, and there are a number of options. A common way round the high-voltage problem is to use a *non-invasive* sensor, which doesn't physically touch the conductor of interest; for example a Rogowski coil, or a current transformer (CT). These work by sensing the magnetic field induced in the coil/transformer by the current flowing in the AC-carrying wire. Current induced in the Rogowski coil is then measured with special circuitry involving an integrating amplifier. A burden resistor in the transformer provides a voltage drop, which can then be measured to calculate the current. In general, AC current measurement is more

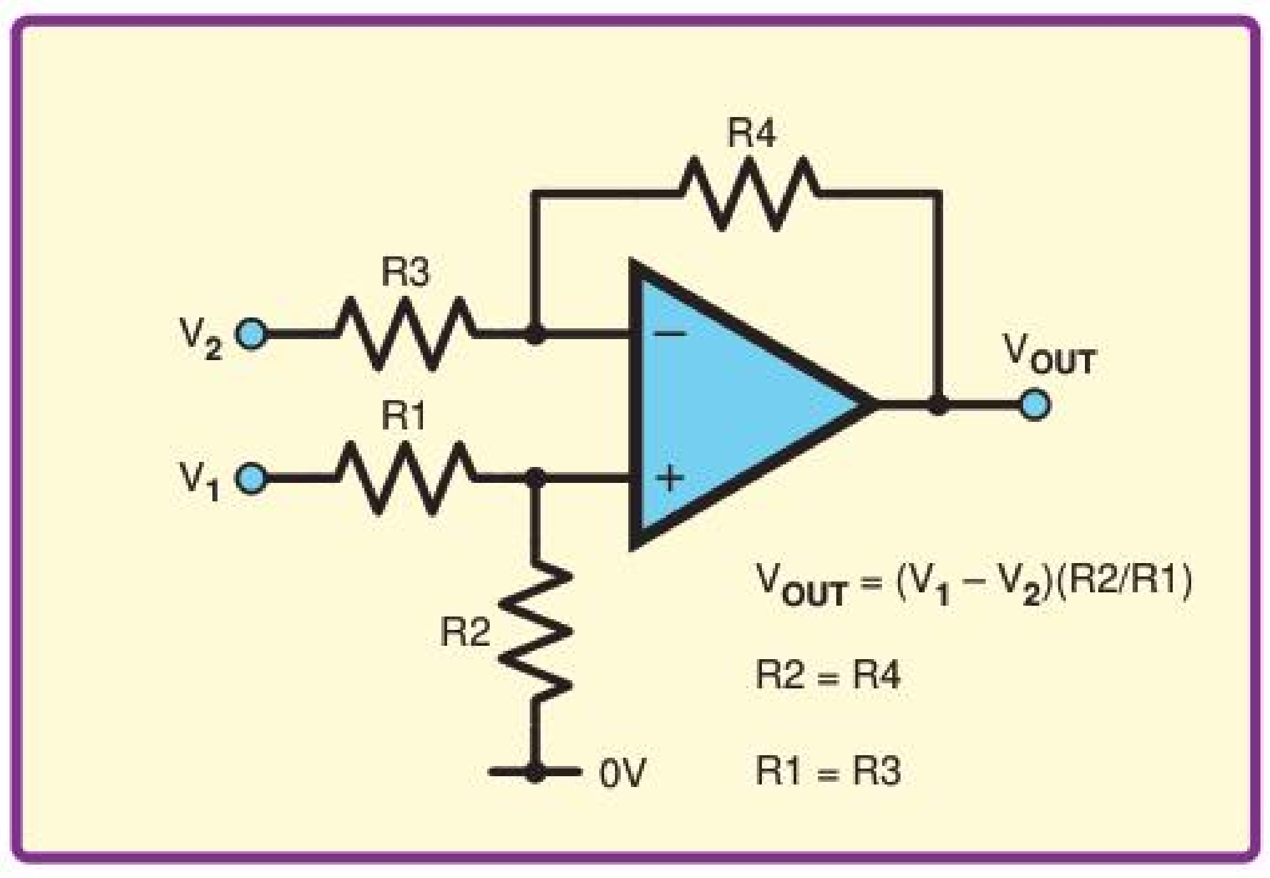

R4
R3
V_2
R1
V_1
V_{OUT}
R2
0V
$V_{OUT} = (V_1 - V_2)(R2/R1)$
R2 = R4
R1 = R3

Fig.2. Difference amplifier

complicated than measuring DC, so for now we will leave it, but we may come back to it later.

DC measurement details

Let's return to measuring DC using a shunt. One important principle of measurement is that the process of measurement should alter the parameter being measured as little as possible. This presents us with an important design issue. We want our signal to be as large as possible, but that means pushing up the shunt's resistance. But, a large resistance will load the circuit being measured. At best this is a waste of energy, at worst it will actually alter the value we are trying to measure.

If we measured the voltage dropped across the shunt resistor as 0.005V (or 5mV) and the shunt resistor is 0.1Ω, we can manipulate our equation : $V = I \times R$ to isolate the current 'I' as $V/R = I$. 0.005V/0.1Ω = 0.05A or 50mA.

Let's look at this another way. With the 12-bit ADC in the PIC, we have a resolution of 3.3V/4096 = 0.0008V per bit. If we want to measure a current of 5mA and have a reasonably large output of 0.005V then we'd need a shunt resistance of: $R = V/I$ = 0.005V/0.005A = 1Ω. That's quite a large value and might well load a circuit. Using a lower shunt value of 0.1Ω, the shunt should present very little load to almost any circuit we are likely to encounter. But now 50mA will produce a tiny voltage: $V = I \times R$ = 0.05A × 0.1Ω = 0.005V. This is now represented by only 6 bits in the PIC, so even if it's detected the accuracy will be severely compromised by a resolution issue. 50mA is hardly a tiny current, and we'd like to get down to at least 1mA, possibly even microamps (µA); so what's the way out of this problem?

Operational amplifiers

The answer to this engineering dilemma is to use a low-value shunt to avoid loading the circuit and then amplify the signal with an op amp so we can measure it with the PIC's ADC.

Op amps are high-gain voltage amplifiers with two inputs and a single output. The output can be hundreds or even thousands of times larger than the signal on its inputs. The gain is calculated by dividing the voltage output by the voltage input (V_{OUT}/V_{IN}). There are many different configurations for an op amp amplifier, but since we are measuring

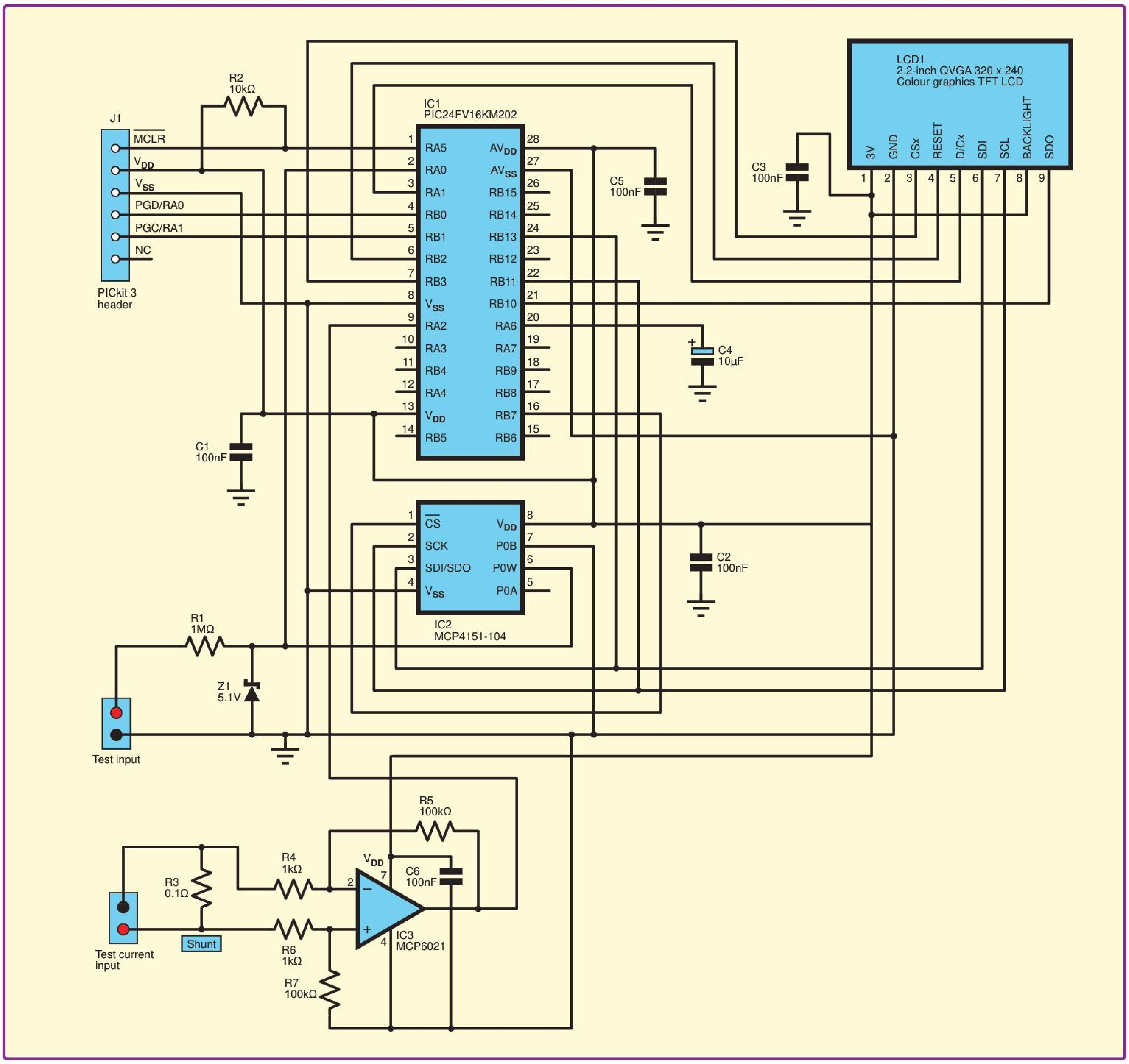

LCD1
2.2-inch QVGA 320 x 240
Colour graphics TFT LCD
3V
GND
CSx
RESET
D/Cx
SDI
SCL
BACKLIGHT
SDO
1 2 3 4 5 6 7 8 9
R2
10kΩ
J1
MCLR
V_{DD}
V_{SS}
PGD/RA0
PGC/RA1
NC
PICkit 3
header
IC1
PIC24FV16KM202
RA5
RA0
RA1
RB0
RB1
RB2
RB3
V_{SS}
RA2
RA3
RB4
RA4
V_{DD}
RB5
AV_{DD}
AV_{SS}
RB15
RB14
RB13
RB12
RB11
RB10
RA6
RA7
RB9
RB8
RB7
RB6
C5
100nF
C3
100nF
C4
10µF
C1
100nF
IC2
MCP4151-104
CS
SCK
SDI/SDO
V_{SS}
V_{DD}
P0B
P0W
P0A
C2
100nF
R1
1MΩ
Z1
5.1V
Test input
R5
100kΩ
R4
1kΩ
R3
0.1Ω
Shunt
Test current
input
V_{DD}
C6
100nF
R6
1kΩ
R7
100kΩ
IC3
MCP6021

Fig.3. Updated schematic showing the addition of the difference amplifier circuit

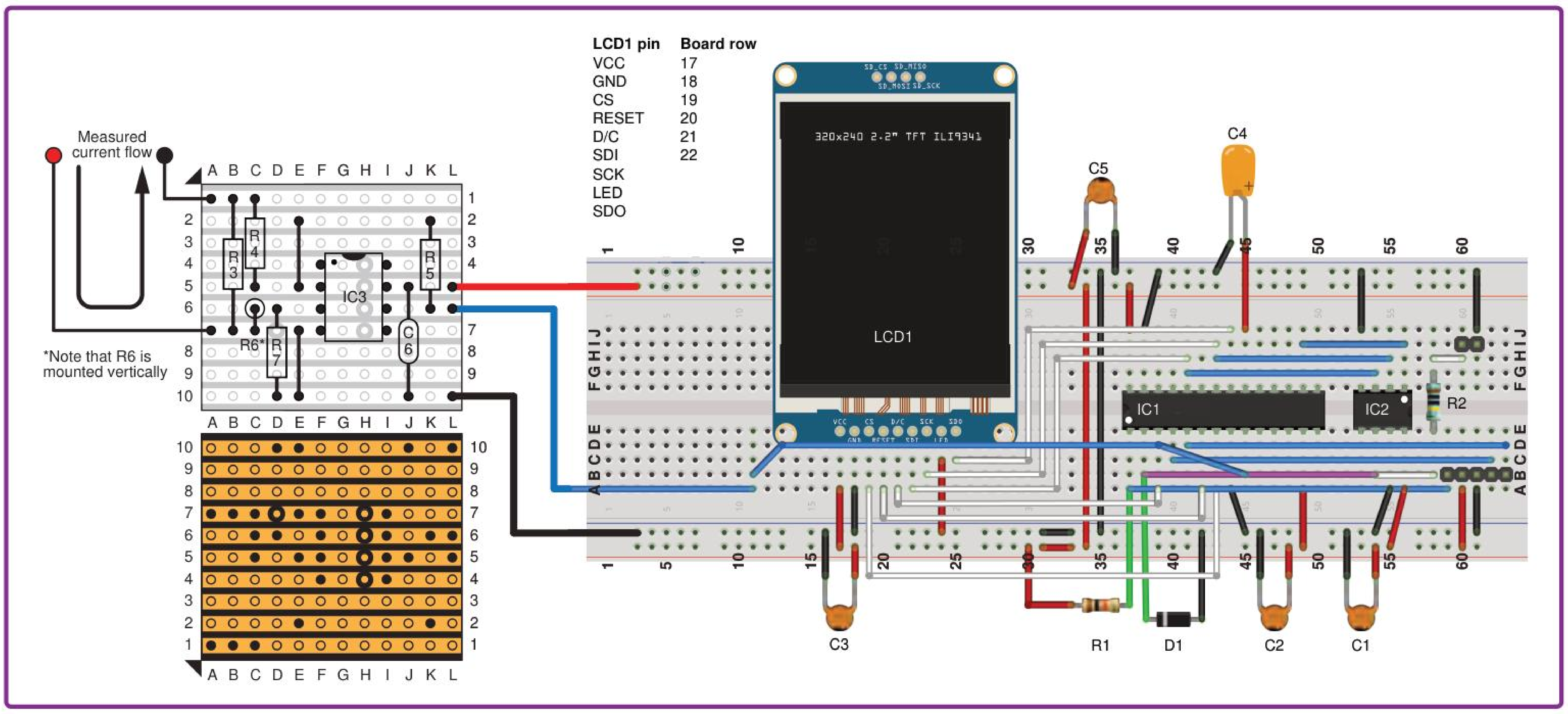


Fig.4. Updated breadboard diagram of PICMeter

a voltage *across* a shunt we will use a difference amplifier, which as its name implies, measures the difference between the voltage at two points – see Fig.2. In this particular arrangement it is common to design the circuit such that R1 = R3, and R2 = R4. Providing these resistor pairs are well matched, the gain of the circuit is simply given by: gain = R2/R1. The output voltage is given by: $V_{OUT} = (R2/R1)(V_1 - V_2)$.

There is one slight problem with this, what happens if the input voltage is amplified to give a voltage higher than the PIC can handle? The short answer is the PIC will be damaged or destroyed. To prevent this from happening, we will use what's known as a 'rail-to-rail' op amp. This means the output of the op-amp is limited to the maximum voltage of the system (which we can decide is the same as the PIC's maximum) and limited to a minimum of the ground voltage in the system. In our circuit that is 3.3V and 0V. Note that this means the op amp's output will not go negative, something which could also damage the PIC.

There are plenty of rail-to-rail op amps available that can operate at 3.3V, Microchip provides a low-cost option, the MCP6021. The device is available in a DIP through-hole package, which can be used in breadboard, veroboard or a through-hole PCB.

Fig.3 shows the updated schematic, including the new difference amplifier circuit using the MCP6021 rail-to-rail op amp and a 0.1Ω shunt resistor. Don't forget to add a 100nF ceramic capacitor for decoupling on the V_{DD} pin of the op-amp. Fig.4 shows the breadboard layout of the circuit (note how busy the bread board is looking!).

Let's look a little closer at the difference amplifier. The 1kΩ input resistors (R4 and R6) should ideally be identical. The same is true for the 100kΩ feedback resistor R5 and R7. Using R4 = R6 = 1kΩ and R5 = R7 = 100kΩ, the gain of the circuit is 100kΩ/1kΩ = 100. While 1% tolerance resistors will do for this circuit (do not use 5% or worse), any small differences between the paired resistors will cause variation in the output gain and compromise it's common-mode rejection. Plus, the very low value of the shunt resistance meant that it was important to keep track resistances to a minimum, which means we should avoid breadboard. So, this sub-circuit was built on a small piece of veroboard – see Fig.4.

Testing the circuit

It's important to test the circuit to verify it works as expected over a range of currents. Fig.5 shows a simple test setup with a 100Ω resistor, 1kΩ potentiometer and a 3V battery. The 100Ω resistor limits the maximum current to 30mA (3V/100Ω), which is useful when the potentiometer is turned down to zero. With the potentiometer turned to the maximum, we obtain a minimum of 2.7mA = 3V/(1kΩ + 100Ω). Now we have our circuit, we'll need some code.

The code

The electronic components have taken care of the process of converting the current into a voltage that can now be read by the PIC. This is done using the analogue-to-digital converter (ADC) peripheral inside the PIC. In Fig.3 the output of the op amp circuit is connected to pin 9 or RA2 of the PIC. This is Port A2, which is also analog pin 13 (AN13). It is from AN13 that we obtain our ADC value. Once we get the value in bit form, we can perform a quick equation to calculate the measured current.

```
#define SHUNT 0.1
#define GAIN 100
#define VOLTAGE_IN 3
#define MAX_BIT_VAL 4096
uint16_t adc_val = 0;
float current_meas = 0;
```

Before we capture any values, we need to determine the above 'hard-coded' values, which are not going to change. The shunt value is 0.1Ω, and our gain is 100. The ADC output is based on the PIC's main voltage, so we need to know what that voltage is. The PICKit3 is used to power this example circuit for 3.25V, but the measured voltage was actually very close to 3V.

We're using a 12-bit ADC, so the maximum bit resolution is $2^{12} = 4096$.

The last two items are important. First, since our ADC value is 12-bit, an 8-bit unsigned integer `uint8_t` would not suffice. We need to use a 16-bit unsigned integer `uint16_t`, which is not a problem because our PIC is a 16-bit device (PIC24F16KM202).

The last item is our current measurement value `current_meas`, which is instantiated as a floating point number. `float` is an interesting data type, which allows numbers with a decimal point of up to ten digits to the right of the decimal point in the 16-bit PIC. How this number is converted into binary and used is a little too complicated to easily explain here; there are issues with using floating-point numbers in embedded microcontrollers in that they are not designed to use them. However, since we are only performing basic mathematics on the number, we should be fine.

Not all of Mike's technology tinkering and discussions make it to print. You can follow the rest of it on Twitter at: @MikePOKeeffe

You'll also find him on *EEWeb* forums as *'mikepokeeffe'* and from his blog at *mikepokeeffe.blogspot.com*

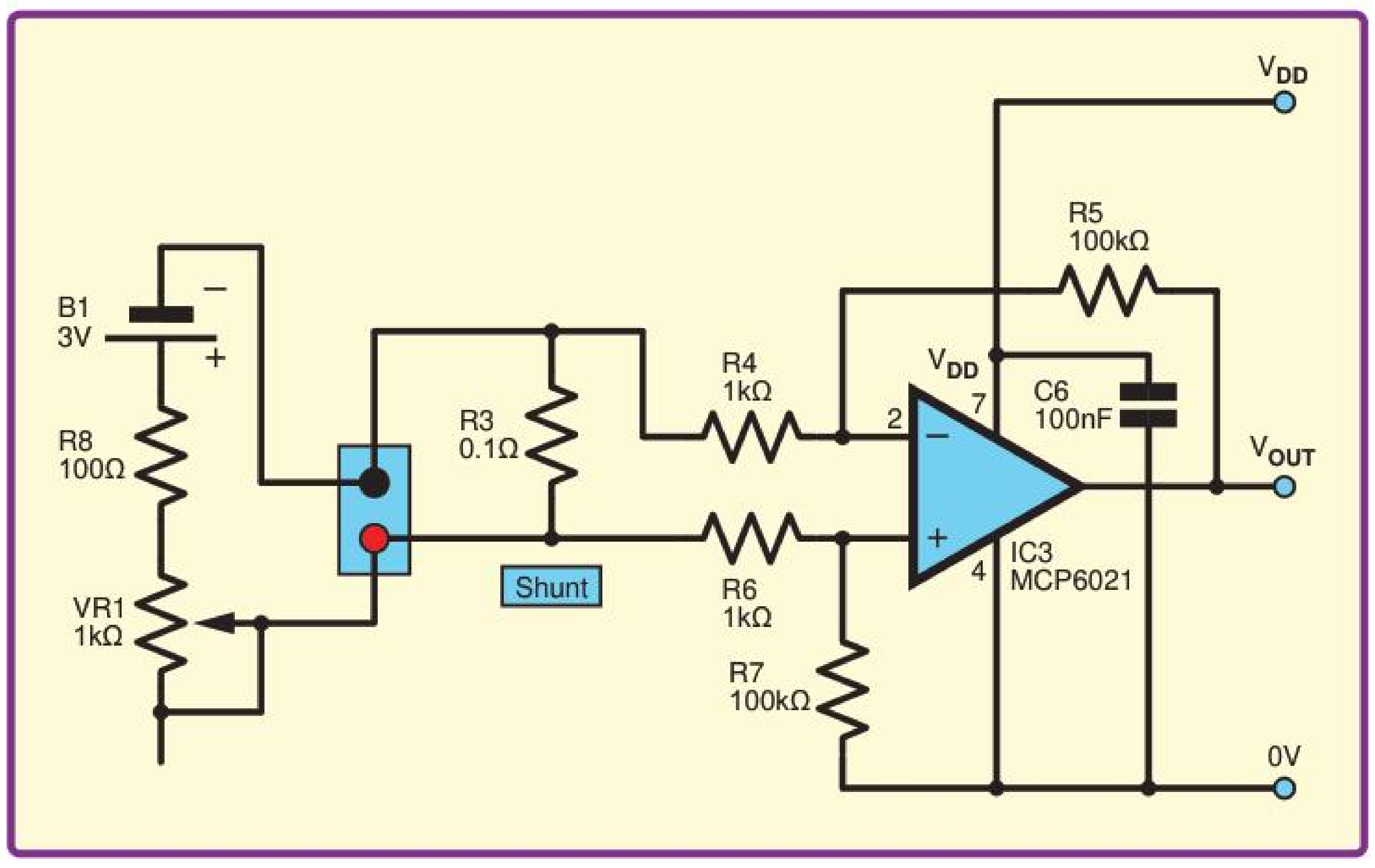


Fig.5. Test 100Ω resistive load and 1kΩ Potentiometer

```
ADC1_ChannelSelect(ADC1_CHANNEL_AN13);
__delay_ms(100);
ADC1_Start();
adc_val = ADC1_ConversionResultGet();
ADC1_Stop();
```

Next, we capture the ADC value from the output of the op amp. Last month, we measured voltage on another ADC input, and we want to keep that functionality, so we'll use the function `ADC1_ChannelSelect()` to change which ADC input we are looking at when measuring current. A small delay to allow the changeover is done before obtaining the ADC value.

```
current_meas = adc_val * VOLTAGE_IN;
current_meas = current_meas / GAIN;
current_meas = current_meas / SHUNT;
current_meas = current_meas / MAX_BIT_VAL;
```

The four lines above could realistically be re-written as:

```
current_meas = (adc_val * VOLTAGE_IN) / (GAIN
* SHUNT * MAX_BIT_VAL);
```

However, for debug purposes it's a good idea to be able to check the values through each step of the equation. This equation converts the binary value captured on the ADC pin, converts it to a relative voltage and finally calculates the corresponding current being passed through the shunt resistor.

Verifying the output

All of the code can be downloaded from the *EPE* website. Once the main circuit and test circuit has been built and the PIC has been programmed, we should be able to see what the captured current value is. With the potentiometer turned all the way to zero, the 100Ω is the only load. With a voltage of 3V, the measured current should be 30mA ($V/R = 3/100 = I$). This value might be slightly off. Remember, we don't have a precise reference voltage for the ADC, just the PIC power rail and the gain of the difference amplifier is not precisely known (close to, but probably not exactly 100). Plus, the values of the load and shunt resistor need to be known precisely to predict the actual value of the current being measured.

Do note that this circuit should be used in low-side current measurement mode, not high-side. While the voltage drop across the shunt remains pretty low and shouldn't cause a problem, in high-side situations the common-mode voltage could present a large voltage difference between the circuit being measured and the PIC circuit. This larger voltage could damage the circuit. There are other ways to get around this, but they are more complicated and/or expensive.

Next month

Our design has gone as far as it can go on a breadboard, so for the next few months we will look at code and using the display. Last, a note about a components. The 10µF capacitor (part FG28X5R1E106MRT06) and the 0.1Ω shunt (part LVR01R1000FE70) – are both available from **mouser.co.uk**

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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Introduction to Circuit Simulation with LTspice – Part 3

FOR THE LAST COUPLE OF MONTHS we have been looking at analogue circuit simulation using SPICE, focusing on how to use LTspice from Analog Devices (see **www.bit.ly/2nsvKzT**). I often use LTspice to help illustrate circuit operation in *Circuit Surgery* articles, and recently we decided to make the files available on the *EPE* website so that readers can more easily try the simulations for themselves. The first article covered some of the history of SPICE, the use of circuit simulation in general and the types of analysis SPICE can perform. We also started working through the process of using LTspice to perform simulations, using the RC circuit shown in Fig.1 as an example (LTspice schematic in Fig.2). The first article concentrated on drawing the schematic and running a transient simulation to look at the waveforms in the circuit.

The second article covered some background on the files used by LTspice, including the SPICE netlist, which is a text file that contains both the description of the circuit and the commands that instruct the simulator which operations to perform. Originally, before the days of graphical users interfaces (GUIs), text input was the only way to set up a SPICE simulation. In LTspice, the netlist is hidden when you run a simulation by drawing a schematic and using the various GUI menus and dialogs to set things up, but it can be seen using `View > SPICE Netlist` (with a schematic selected). LTspice can also run a simulation directly from a netlist file. Users of LTspice may need to deal with text versions of commands/options not covered by the menus, or make use of text descriptions of circuits such as those provided by component manufacturers. The use and syntax of the various commands is defined in the help pages built into LTspice.

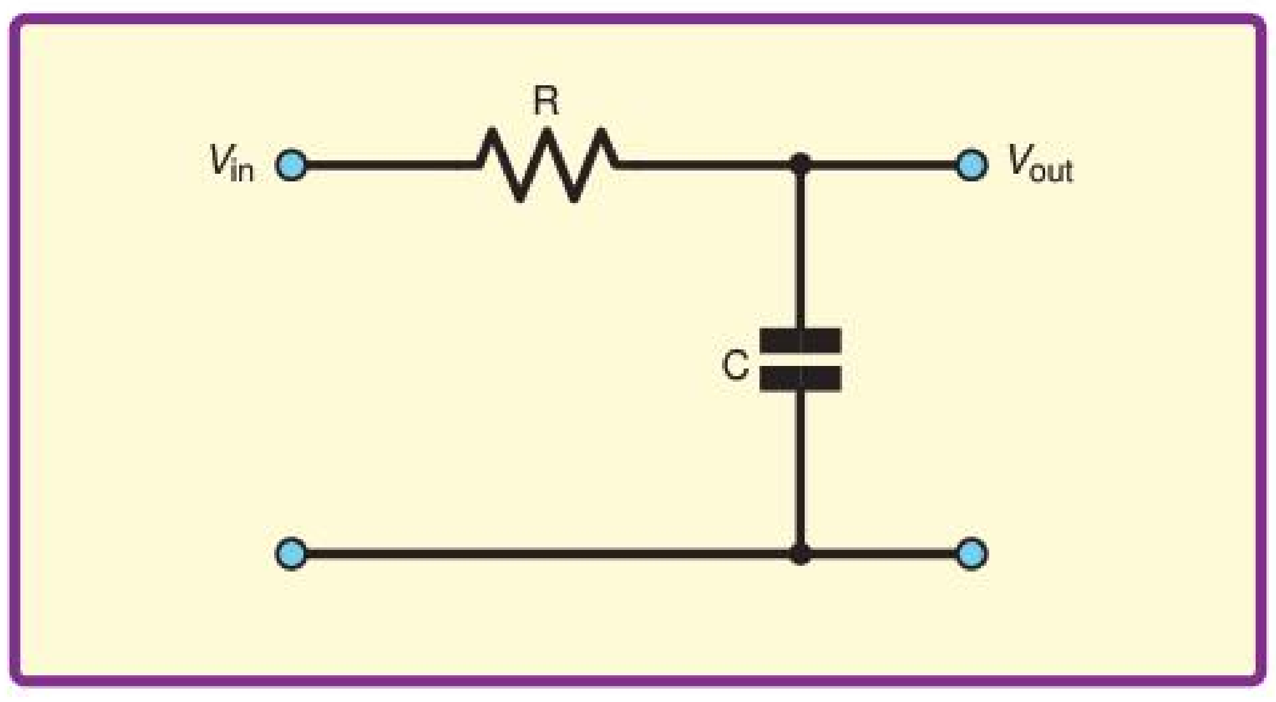


Fig.1. RC circuit simulation example.

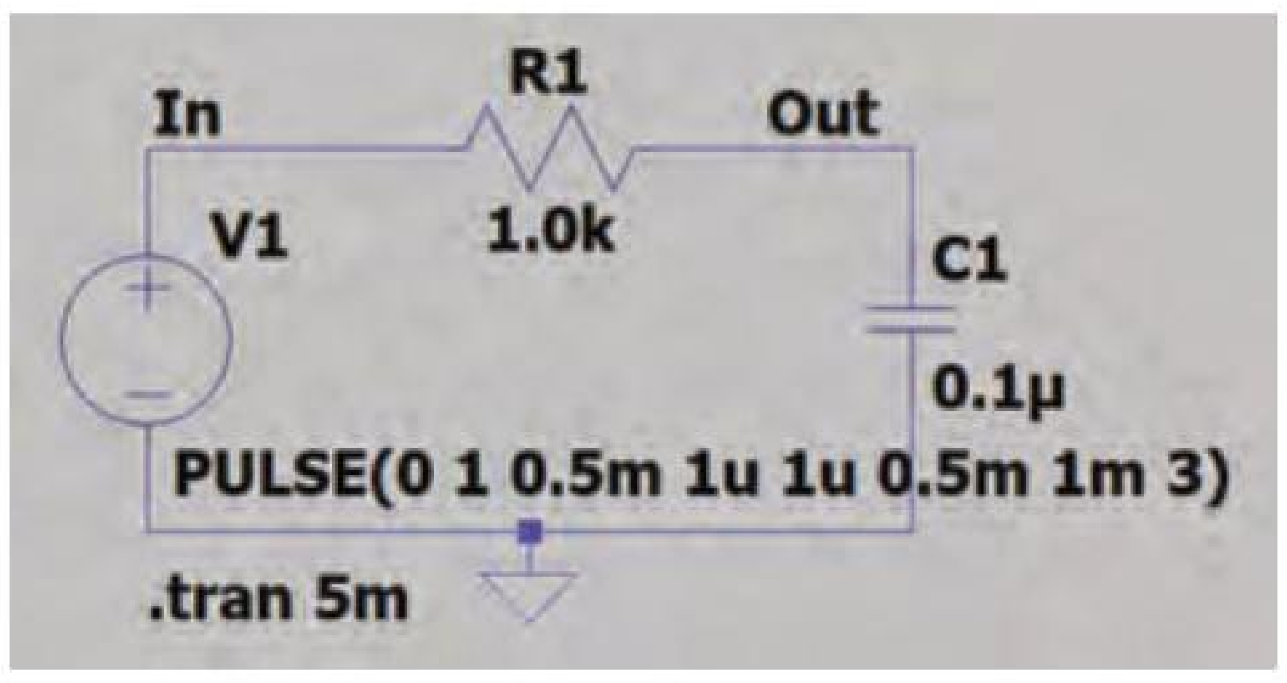
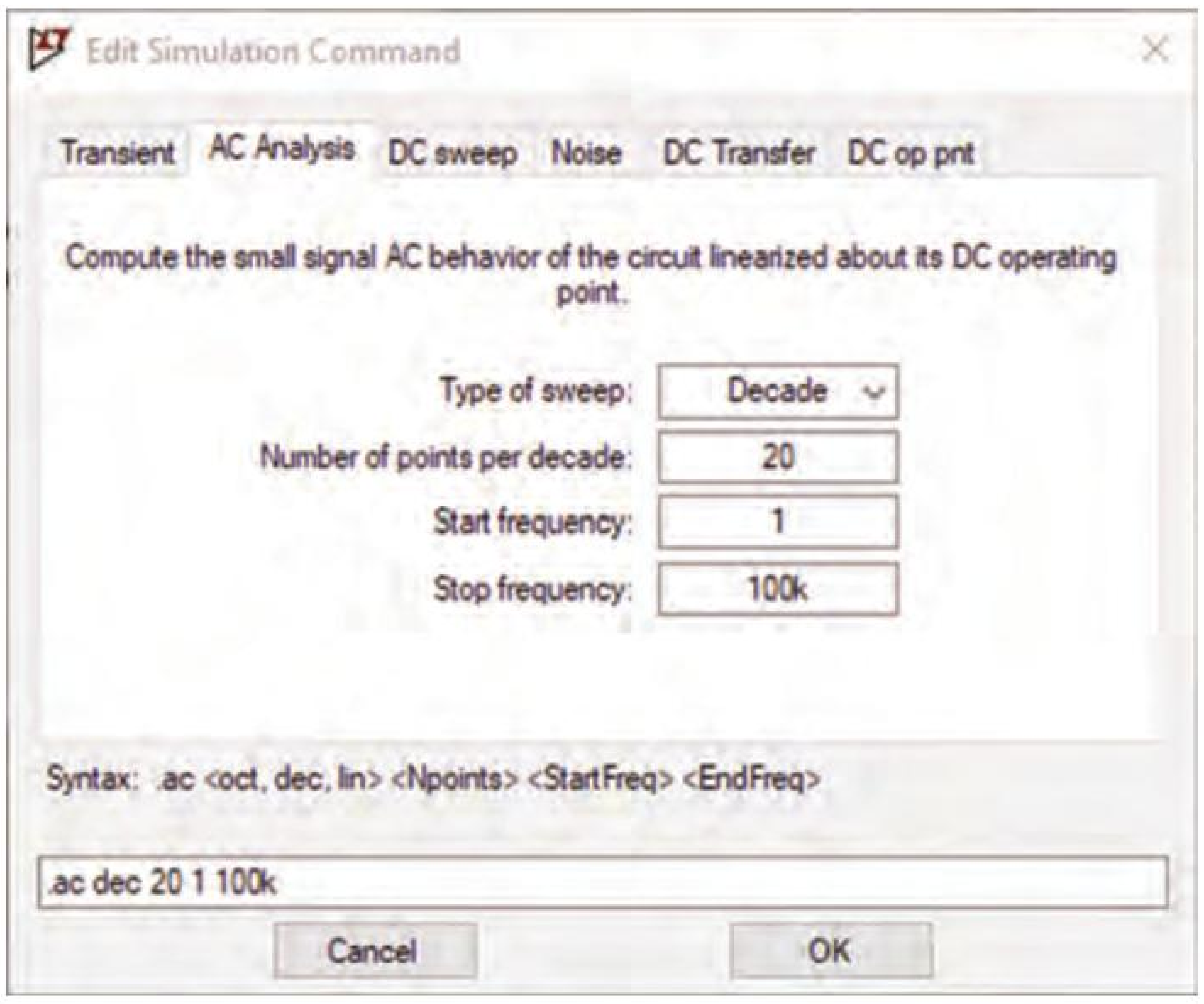


Fig.2. LTspice schematic used last month for transient simulation of the circuit in Fig.1



Compute the small signal AC behavior of the circuit linearized about its DC operating point.

Type of sweep: Decade

Number of points per decade: 20

Start frequency: 1

Stop frequency: 100k

Syntax: .ac <oct, dec, lin> <Npoints> <StartFreq> <EndFreq>

```
.ac dec 20 1 100k
```

Fig.3. Setting up an AC Analysis.

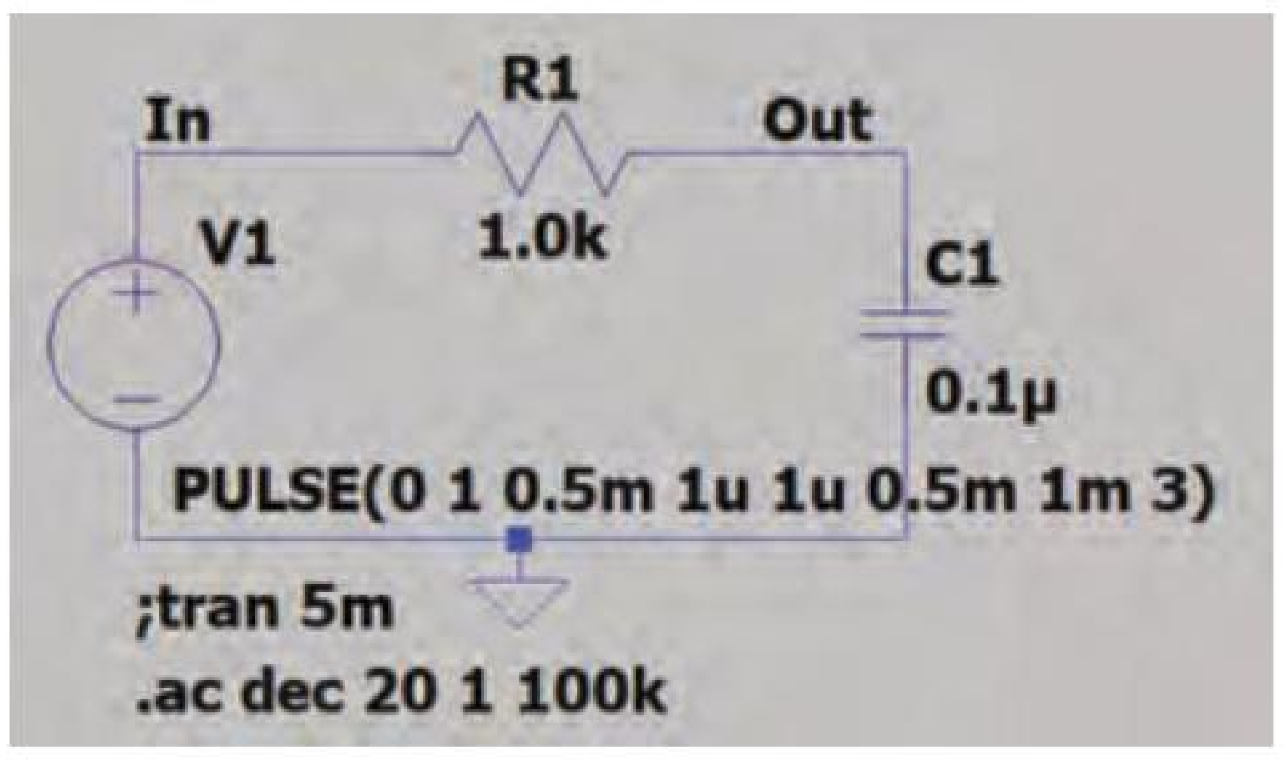


Fig.4. Schematic after configuring the simulation command for AC analysis.

AC analysis

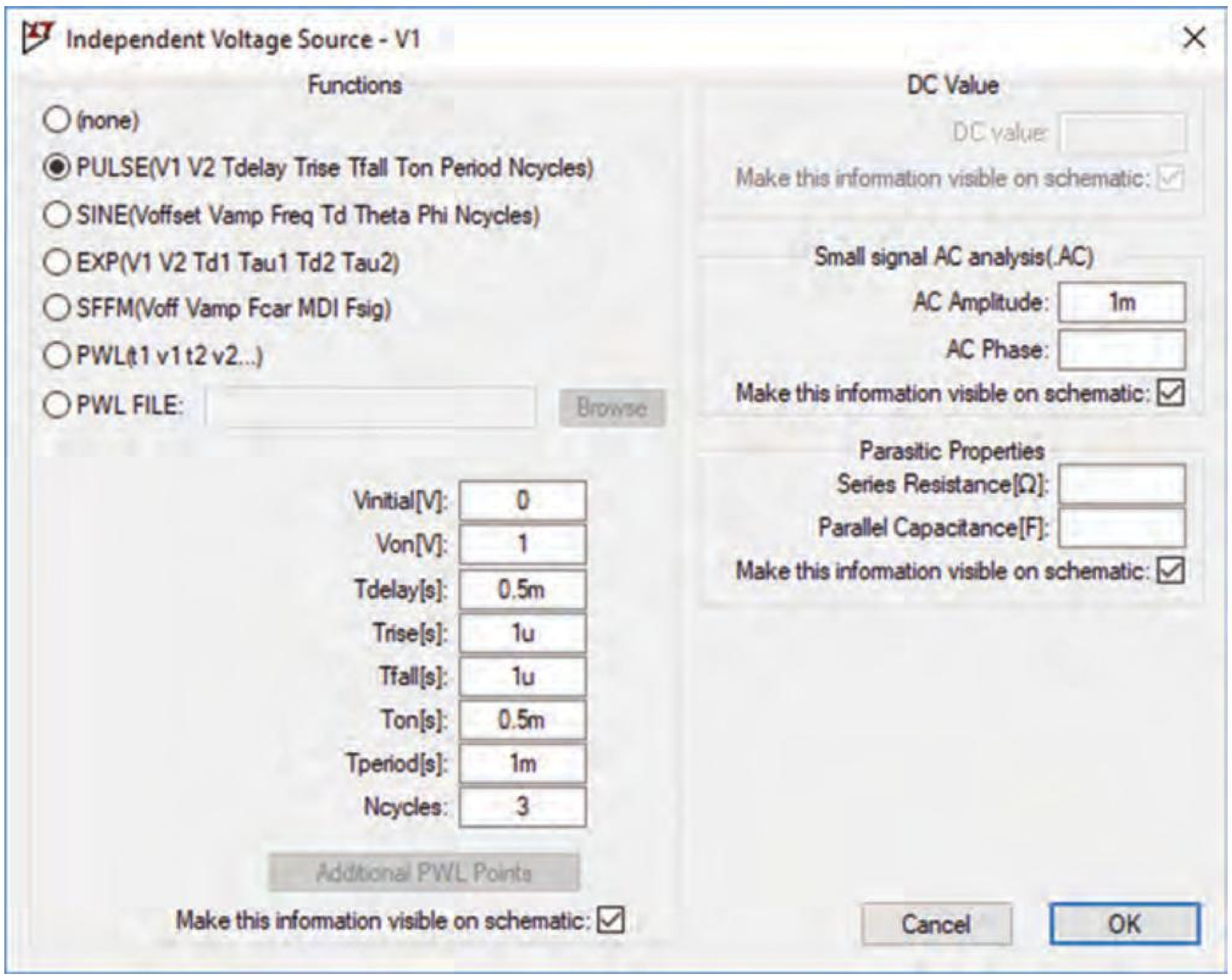
Last month, we also continued with the basic instructions on using LTspice, concentrating on the waveform display for the transient simulation of Fig.2 started in the first article. This month, we will start by again using the circuit in Fig.1 as an example, but this time looking at the frequency response. The frequency response can be obtained by performing an AC analysis, also known as a 'small-signal analysis'. The data from an AC analysis can be represented/plotted in a number of ways, but the frequency response graph, or Bode plot, is one of the most commonly used. This is a graph of both the gain magnitude and phase shift against frequency.

Using AC analysis, SPICE is able to rapidly compute circuit voltages and currents as a function of frequency. This could be done by applying a sinewave input in a transient simulation, measuring the amplitude of the output waveform and calculating the gain, or anything else of interest. One problem with this approach is that it is very slow – many transient simulations have to be run and analysed. Furthermore, if the circuit is nonlinear the output may be distorted, making processing the results more difficult.

To overcome these problems, AC analysis starts by finding the DC operating point of the circuit and then uses linearised models for all of the nonlinear devices at this operating point. To understand how this works, consider a diode (a nonlinear device). With a small forward voltage (below say 0.1V) the diode hardly conducts, so its effective resistance is very high. With a higher forward voltage (above say 0.7V) the diode is fully conducting and has a much lower

Simulation files

The LTSpice files discussed in this month's *Circuit Surgery* are available for download from the *EPE* website.


Independent Voltage Source - V1

Functions

○ (none)

● PULSE(V1 V2 Tdelay Trise Tfall Ton Period Ncycles)

○ SINE(Voffset Vamp Freq Td Theta Phi Ncycles)

○ EXP(V1 V2 Td1 Tau1 Td2 Tau2)

○ SFFM(Voff Vamp Fcar MDI Fsig)

○ PWL(t1 v1 t2 v2...)

○ PWL FILE:

Vinitial[V]: 0

Von[V]: 1

Tdelay[s]: 0.5m

Trise[s]: 1u

Tfall[s]: 1u

Ton[s]: 0.5m

Tperiod[s]: 1m

Ncycles: 3

Make this information visible on schematic: ☑

DC Value

DC value:

Make this information visible on schematic: ☑

Small signal AC analysis(.AC)

AC Amplitude: 1m

AC Phase:

Make this information visible on schematic: ☑

Parasitic Properties

Series Resistance[Ω]:

Parallel Capacitance[F]:

Make this information visible on schematic: ☑

Fig.5. Setting up a voltage source for AC analysis.

effective resistance. This variation of resistance with applied voltage is an example of nonlinear behaviour.

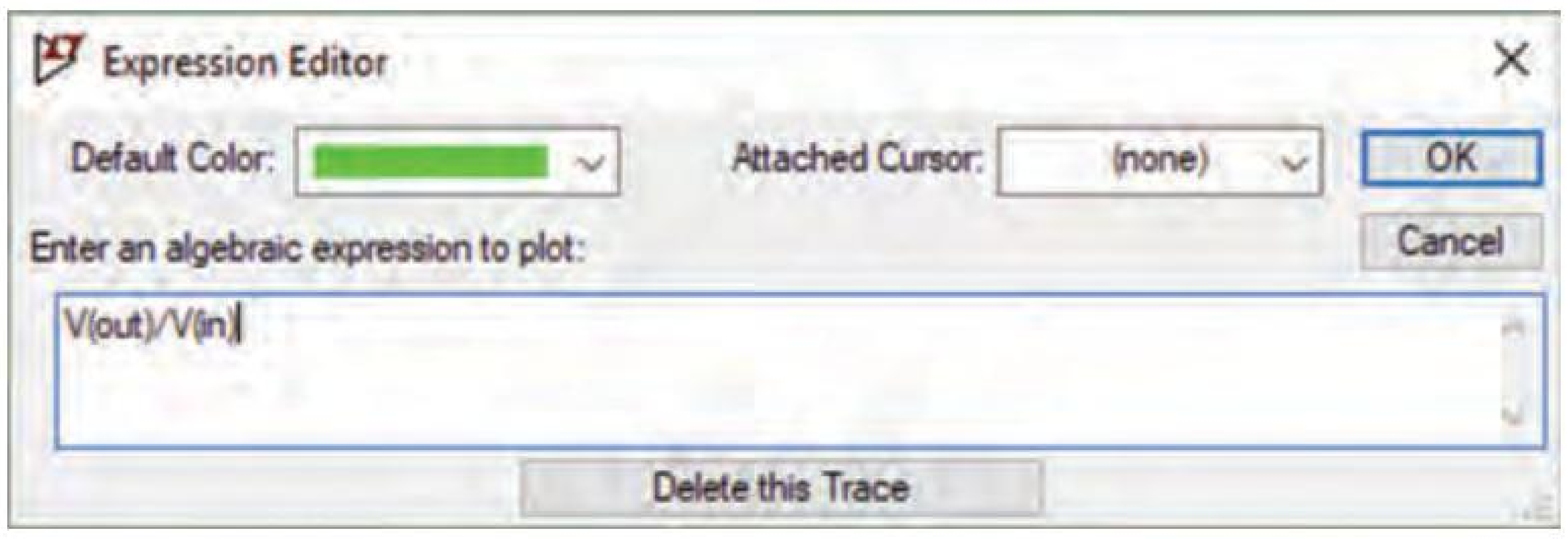
If you plot a graph of current against applied voltage for a resistor you get a straight line (linear), for a diode the line is not straight (nonlinear). In a circuit containing a diode the voltage across the diode with no signal applied (zero input) is the operating point of the diode – this determines the resistance with no signal present. If the signal amplitude is small then the resistance of the diode will not change much as the input signal varies. Under these conditions the diode could be represented by a fixed (linear) resistance (the value at the operating point), rather than having to take into account the full complexity of its varying resistance with voltage. This is the basic idea of a linearised model at an operating point. The assumption of a small amplitude input is why AC analysis is also called 'small-signal analysis'. Using the linearised model reduces the complexity of the calculations required to perform an analysis at many different frequencies.

Expected frequency response

As before, we start by making sure we have some idea of what to expect so that we can set up the simulation appropriately and not be fooled if there is a simulation problem or if we set something up wrong. With an AC input applied, the circuit in Fig.1 acts a low-pass filter with a cut-off frequency (f_c) which is given by: $f_c = 1/2\pi RC$, and at which the magnitude of V_{out} is $0.707V_{In}$ (the gain is 0.707). With the values used in Fig.2 we expect f_c to be: $1/(2\times\pi\times1.0\times10^3\times0.1\times10^{-6}) = 1.59$kHz.

Frequency responses are often plotted over wide frequency ranges of several orders of magnitude (for example 10Hz to 10MHz is a million-fold change, or six orders of magnitude). If a linear scale is used for such wide ranges, the data at the low frequency end is squashed into the left hand side and is invisible. Using a logarithmic frequency scale allows details to be seen throughout the range, so this is commonly done. Similarly, over the frequency range of interest the gain of circuits may vary over several orders of magnitude. Plotting the gain on a logarithmic scale enables details to be seen in the low-gain parts of the range that would be indistinguishable on a linear plot.

Frequency responses are often plotted using units of decibels (dB). The decibel is a logarithmic unit for measuring relative power levels (power ratios). For power gain (output to input ratio) the value in decibels is 10log(P_{out}/P_{in}). Power is proportional to the square of voltage (into a fixed load), so writing the power gain as 10log(V^2_{out}/V^2_{in}) gives 20log(V_{out}/V_{in}) – squaring inside a log is equivalent to multiplying the log value by 2. The formula 20log(V_{out}/V_{in}) is used to express a voltage gain in decibels. To express a single voltage, or power, rather than a ratio of input-to-output in decibels, it is necessary to specify a reference level, for example 1V or 1mW, to which the signal of interest is compared.


Expression Editor

Default Color: 🟩

Attached Cursor: (none)

Enter an algebraic expression to plot:

V(out)/V(in)

Fig.7. Entering the gain expression in the plot expression editor.

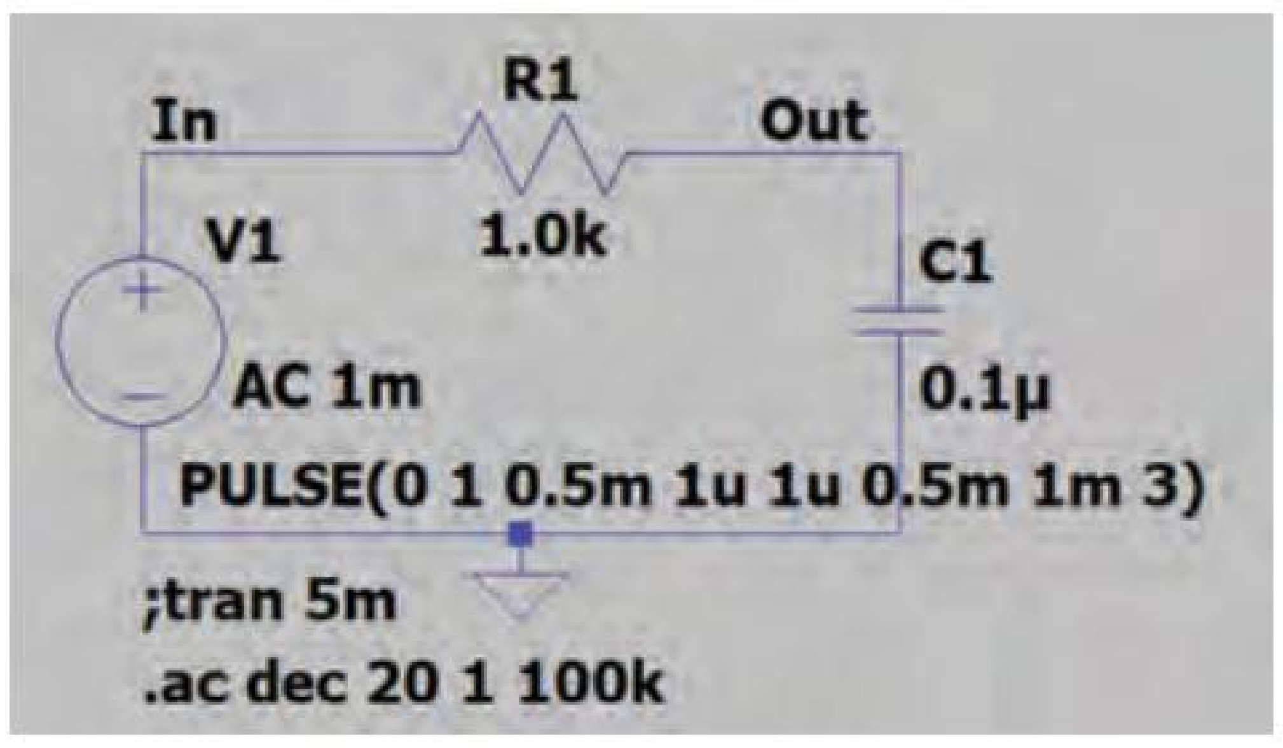


Fig.6. Schematic after configuring the voltage source for AC analysis.

Returning to the circuit in Fig.1, we would expect the frequency response to show a gain of 1 at frequencies much lower than the cut-off (low pass). At these frequencies, the capacitor is effectively an open circuit. A voltage gain of 1 is 0dB (20log(1.0)). As frequency increases towards the cut-off, the gain will start to reduce. Gains of less than 1 are negative when expressed in decibels. The voltage gain of 0.707 (actually 1/√2), which the filter has at the cut-off frequency is a power gain of 0.5 (1/2). This is –3dB in decibels (10log(0.5) = –3). The cut-off frequency, or '–3dB point' of a filter is the frequency at which output power falls to half that in the pass band.

Performing an AC analysis

If you worked through the previous examples, open the schematic (`.asc`) file which you saved at the end of the previous article. Alternatively, work through the previous examples, or simply download the file `LTSpice_Intro2_Fig2.asc` from the *EPE* web site and open it in LTspice. The schematic is currently configured for a transient simulation, as indicated by command (SPICE simulation directive) `.tran 5m` on the schematic. Recall from last month that SPICE directives (in the netlist) start with a full stop. Save the schematic with a new name.

To change the type of simulation performed do: `Edit > Edit simulation cmd` from the main menu (with the schematic selected). In the Edit Simulation Command dialog go to the AC Analysis tab and set Type of sweep to Decade, Number of points per decade to 20, Start frequency to 1 and End frequency to 100k (see Fig.3). This will set up an AC Analysis in which the data points are spread logarithmically over a ten-to-one frequency range (decade sweep), with 20 data points per decade. That is, there will be 20 data points from 1Hz to 10Hz and 20

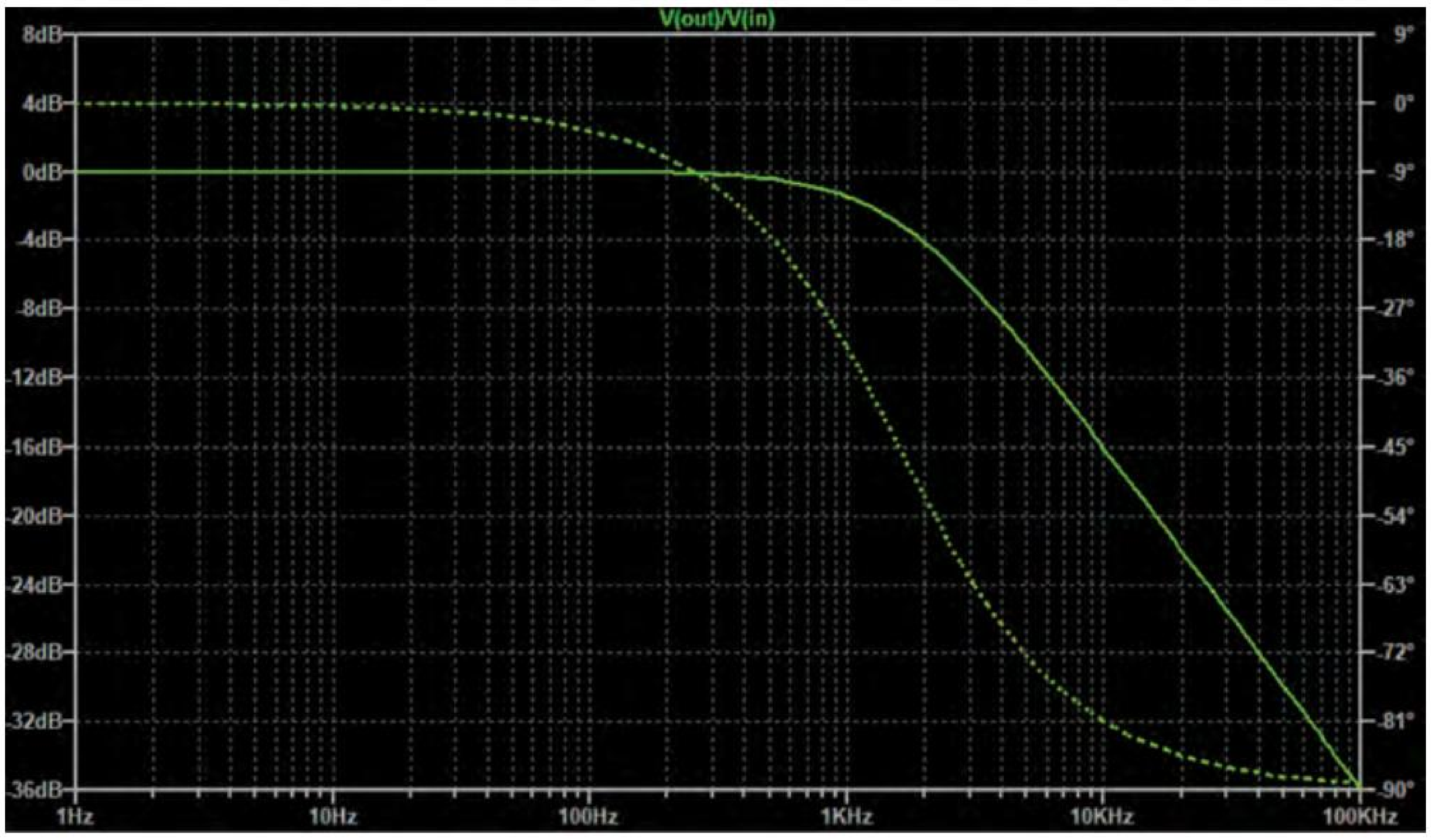
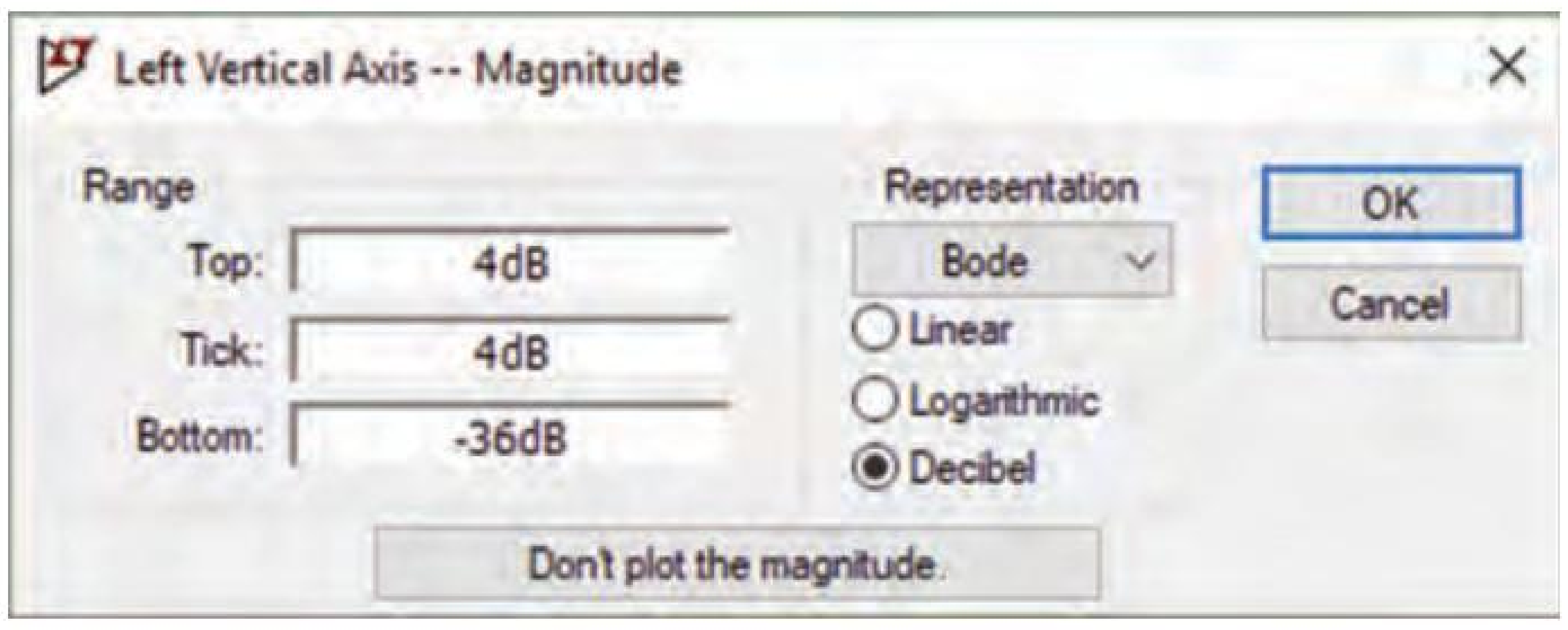


Fig.8. AC Analysis results plot: gain and phase shift of the circuit in Fig.6 vs frequency.



Range
Top: 4dB
Tick: 4dB
Bottom: -36dB

Representation: Bode
○ Linear
○ Logarithmic
● Decibel

Fig.9. Axis configuration for AC analysis results.

data points from 10Hz to 100Hz, and so on, to facilitate plotting on a logarithmic frequency scale. The AC analysis can also perform an octave sweep (data points in a two-to-one range), a linear sweep (data points at fixed frequency intervals) and use a list of specific frequencies.

When you click OK you will see the schematic update to include the SPICE directive for the AC analysis (see Fig.4). The original transient analysis directive is not removed, it is commented out by replacing the initial full stop with a semicolon. If you look at the netlist you will see that it appears there too. Last month, we noted that if the first character of a SPICE netlist is an asterisk then the line is treaded as a comment and ignored by the simulator. LTspice also interprets a semicolon as the start of a comment, wherever it is on the netlist line.

We are not quite ready to run the simulation. AC analysis is based on an input signal source providing a 'small-signal' input at the frequency of interest, so we have to configure a source to provide this. Right click on the V1 voltage source and in the Small signal AC analysis (AC) section enter 1m (for 1mV), as shown in Fig.5. Then click OK in the dialog, which will add the text AC 1m to the schematic near to V1 (see Fig.6). The source is still configured to produce pulses in a transient simulation, but this is not used in the AC analysis, so we do not have to change the Functions section.

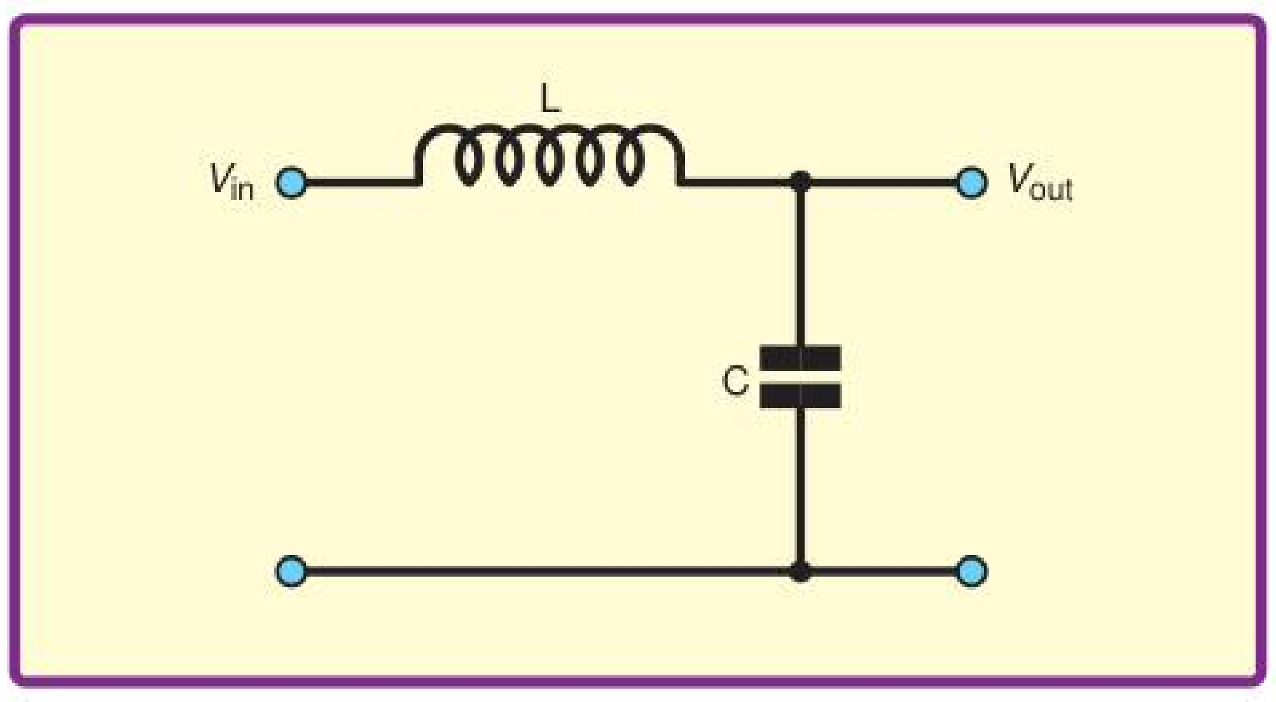


Fig.10. LC circuit to be used a simulation example.

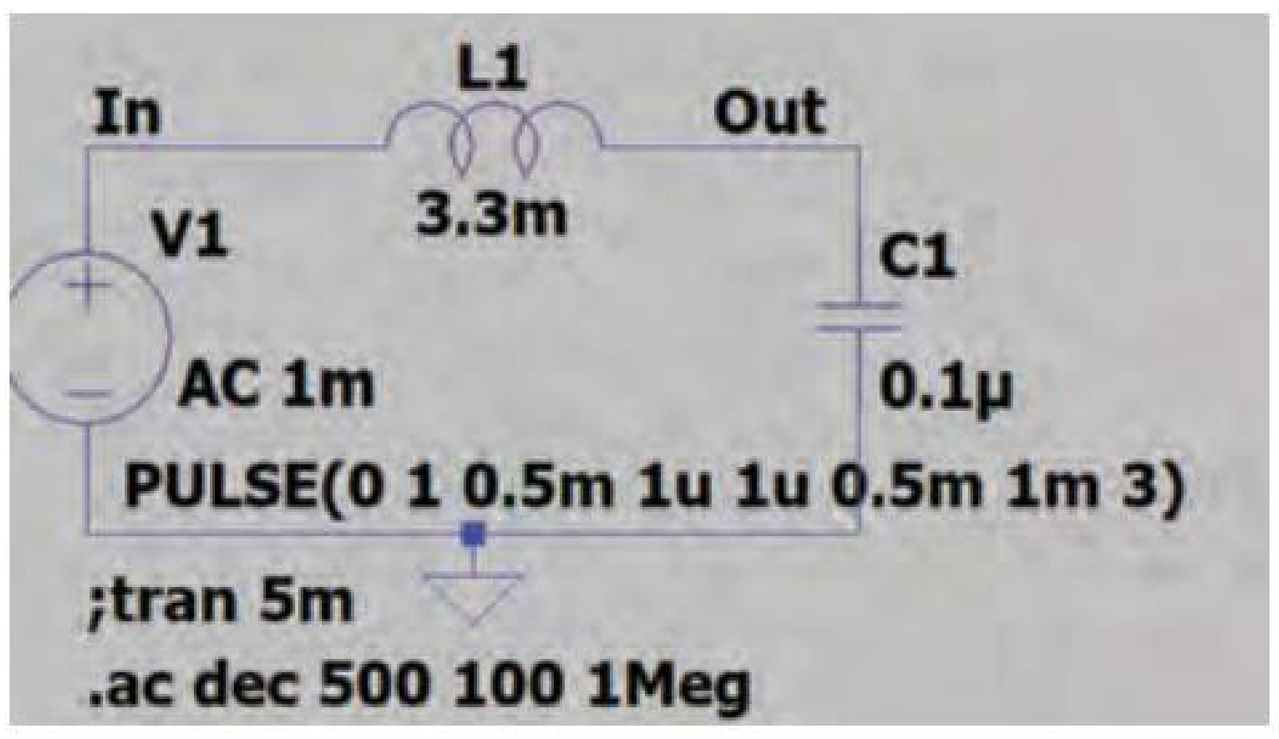
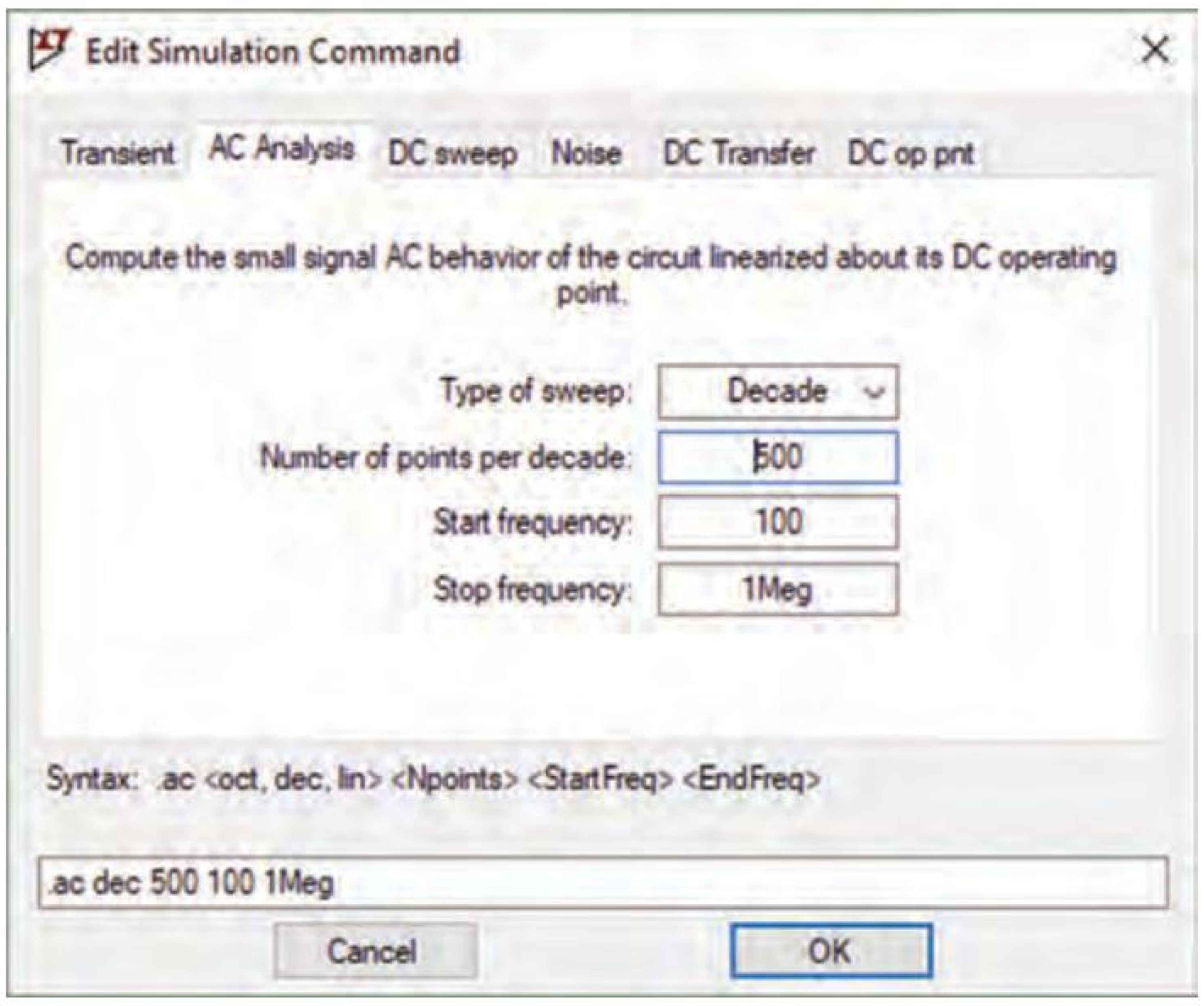


Fig.11. LTspice schematic for LC circuit.



Compute the small signal AC behavior of the circuit linearized about its DC operating point.

Type of sweep: Decade
Number of points per decade: 500
Start frequency: 100
Stop frequency: 1Meg

Syntax: .ac <oct, dec, lin> <Npoints> <StartFreq> <EndFreq>

```
.ac dec 500 100 1Meg
```

Fig.12. AC Analysis settings for LC circuit.

Note the check boxes in the sources dialog, which allow you to control what information is displayed on the schematic. You could remove the PULSE statement from the schematic to make it less cluttered if you wanted. You can also use the Move tool (hand symbol) to reposition text if you need to.

The simulation can now be run using `Simulation > Run` from the main menu. This will open a blank waveform window. Right click on the waveform window background, select Add Traces from the menu select V(out) in the Add Traces to Plot dialog, then click OK in the dialog. A frequency response graph will be displayed.

Plotting options

Take a look at the axis on the left and you will see that the voltage at low frequencies is plotted at –60dB. This does not match our previous discussion, where we anticipated 0dB at low frequencies. There are a couple of issues here to consider. First, as stated earlier, when individual voltages are expressed in decibels this must be with respect to a reference level, but it is not obvious what the reference level is. In fact the reference is 1V; therefore, because we configured the source at 1mV, the value of V_{out}, with a gain of one, is at 1/1000 of the reference, which is equal to –60dB.

If you were to go back to the source and set the voltage to 1V and rerun the simulation the plot would start at 0dB at low frequencies. However, plotting just `Vout` is not really what we want. We are interested in the gain of the circuit V_{out}/V_{in} not just V_{out}. We can get LTspice to plot this. Right click on the `V(out)` signal name at the top of the waveform display. This will open the Expression Editor dialog, which we looked at last month in the context of using the cursors. In the 'Enter an algebraic expression to plot:' box modify the text so that it reads `V(out)/V(in)`, as shown in Fig.7. Click OK. The waveform display will update to display the gain calculated using V_{out}/V_{in} (see Fig.8), which will be 0dB at low frequencies whatever AC voltage is configured for the V1 source. You do not have to use the Expression editor to change the waveform after plotting, expressions can be entered using Add Traces. For details of the all maths functions you can use search for 'waveform arithmetic' in help.

The display of AC analysis results defaults to log frequency and dB amplitude/gain scales. The phase response (phase shift from input to output) is also plotted. The gain scale is on the left and the phase scale on the right. If you only want to plot one of these, right click on the scale you don't want (over the axis numbers, not in background of the plot, cursor rule-shaped) and click the 'don't plot' button in the Axis dialog (eg, Fig.9).

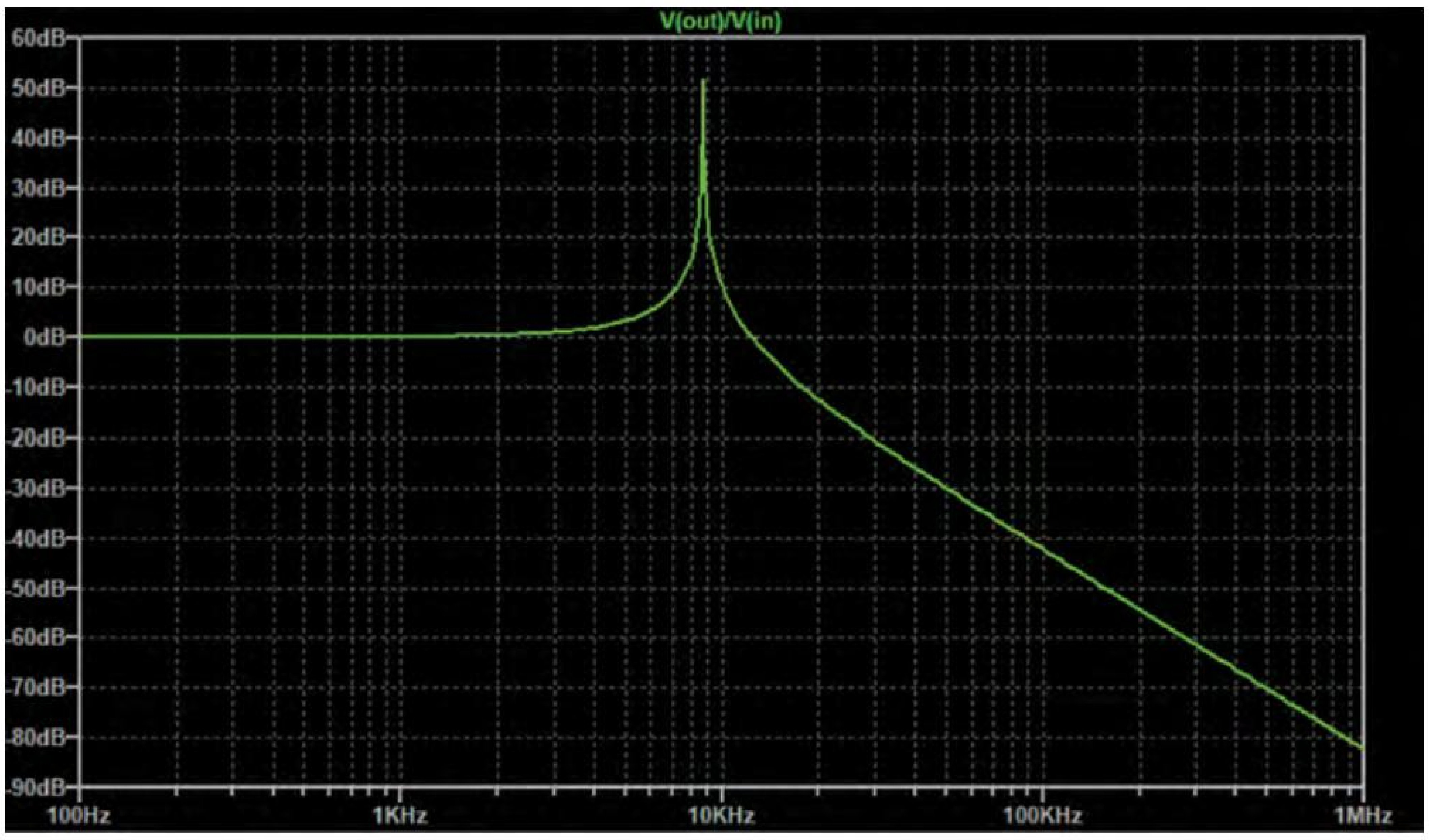


Fig.13. AC Analysis results for circuit in Fig.11.

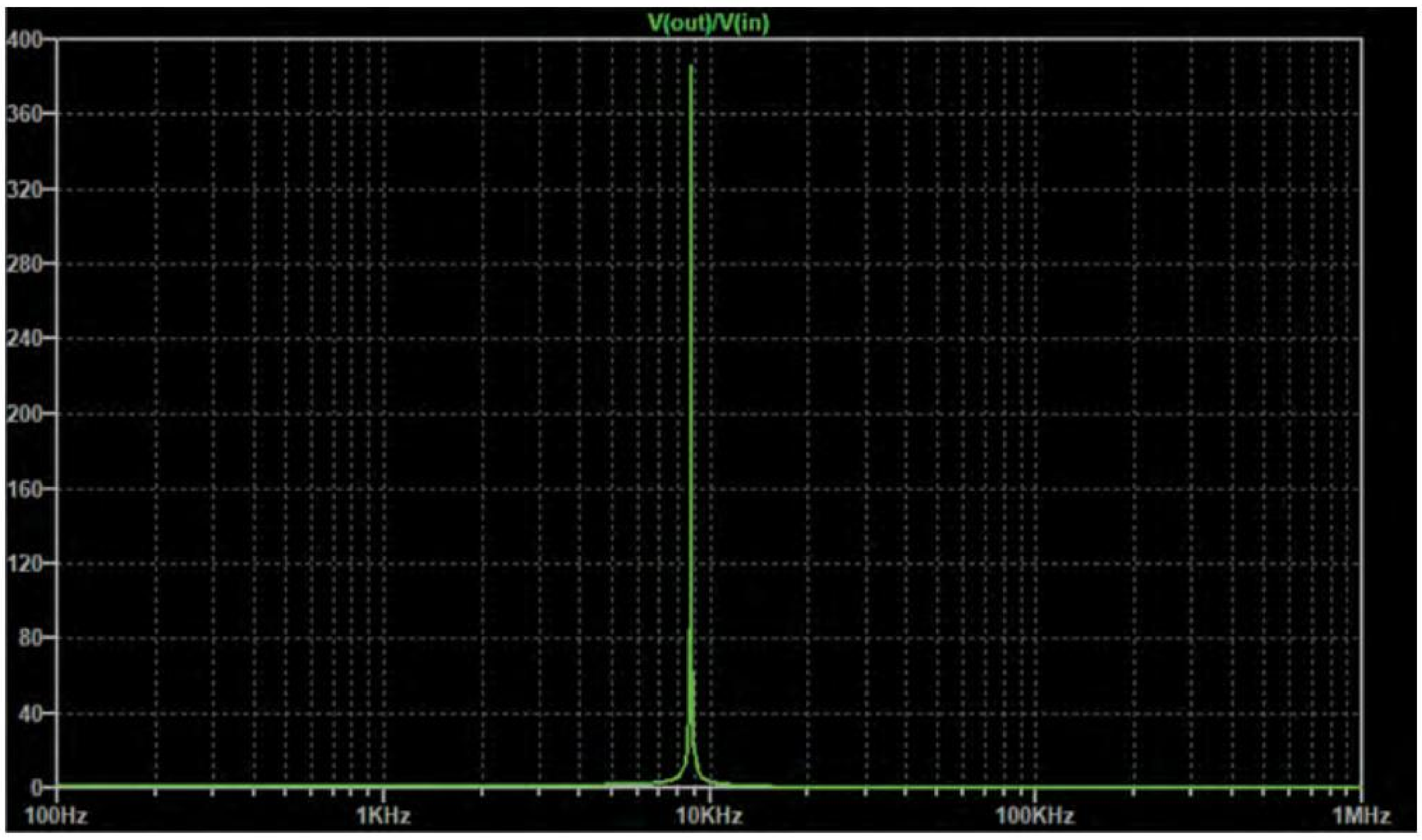
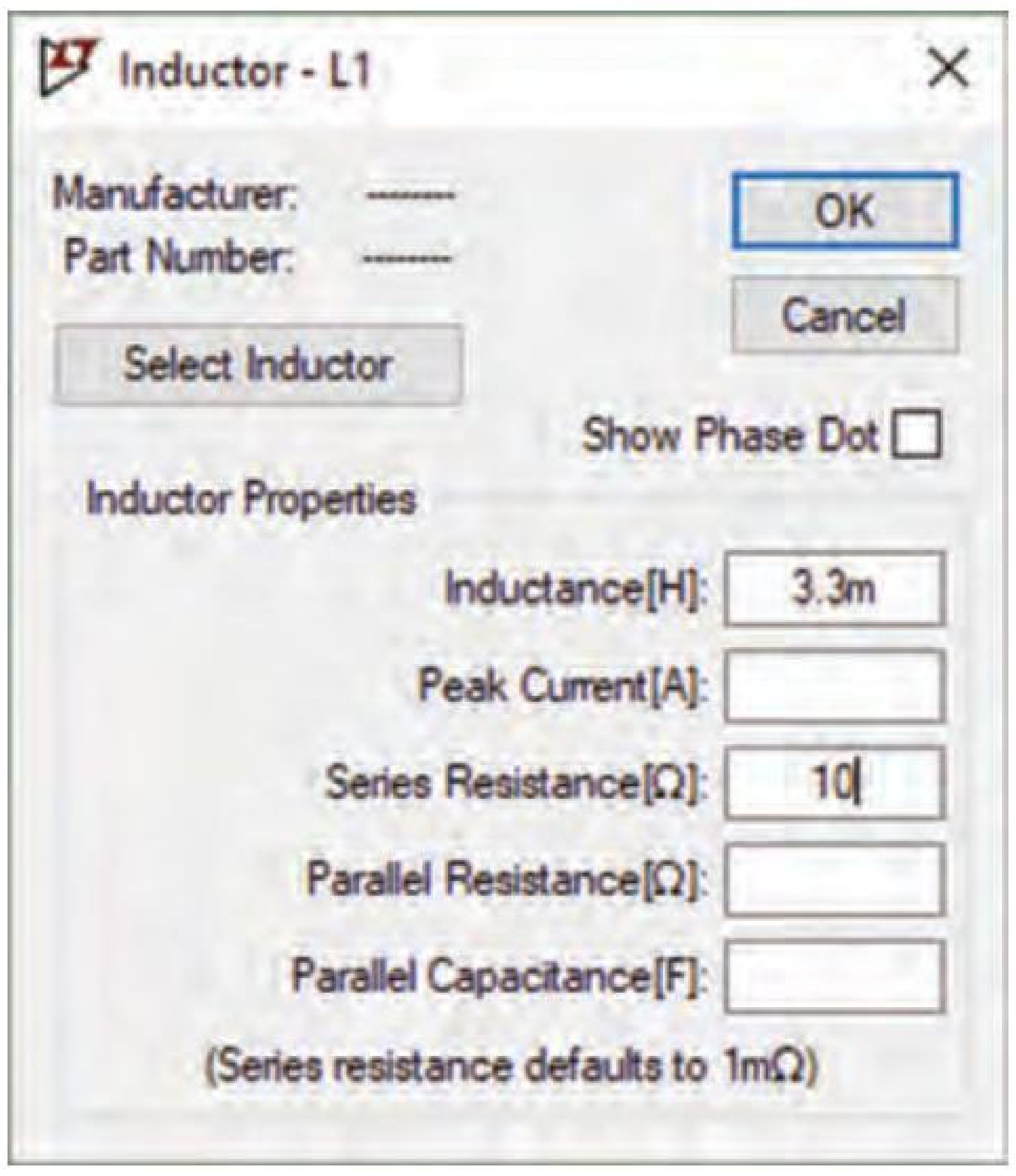


Fig.14. The data from Fig.13 plotted with a linear gain axis – the low-pass behaviour is not visible.

As we saw last month, this dialog can also be used to set the range and tick value of the axis. For AC analysis results we can also select the data representation, which defaults to the Bode plot of Fig.8. It is also possible to create Nyquist plots (typically used to analyse stability) and to plot the real and imaginary parts of the signal (Cartesian). We will not discuss the theory related to these here, but if you are familiar with these concepts you may wish to make use of this facility. The magnitude for the Bode plot can be plotted in decibels, on a log scale, or on a linear scale. Fig.8 includes a grid in the background of the waveform. This can be switched on and off by right clicking in the back ground, selecting View from the menu and toggling between the Grid option as required.


Inductor - L1

Manufacturer: --------

Part Number: --------

Inductor Properties

Inductance[H]: 3.3m

Peak Current[A]:

Series Resistance[Ω]: 10

Parallel Resistance[Ω]:

Parallel Capacitance[F]:

(Series resistance defaults to 1mΩ)

Fig.15. Setting inductor series resistance.

LC circuit example

The circuit in Fig.10 is an LC low-pass filter. A key feature of this circuit is that it exhibits resonance. The physics of resonance involves the efficient transfer of energy between different forms. Capacitors and inductors both store energy (in electric and magnetic fields) and transfer the energy easily via current flow. An ideal LC circuit, with no resistance present, will store all input energy provided at the frequency at which the L-to-C energy exchange occurs, resulting in infinite gain. The resonant frequency (f_0) is given by: $f_0 = 1/2\pi\sqrt{(LC)}$.

The frequency response of the circuit in Fig.10 differs from that of Fig.1 in that there is a sharp peak in gain at the resonant frequency. The peak requires a lot of data points to plot accurately. We will use this to illustrate the effects of some settings – simulation command and plotting options can be important in getting meaningful results from the simulator. The infinite-gain ideal behaviour at resonance raises the issue of how 'real' our simulation is and what we might do about it.

LC circuit simulation

To start working on the LC circuit, first save the current schematic (if you have not done so already) and then use `File > Save As` to save the file with a different name. Edit the schematic to replace the resistor with a 3.3mH inductor, as shown in Fig.11. To delete components or wires, hit the delete key and click on the schematic with the scissor icon. Hit the escape key to stop deleting. Click the inductor button to add the inductor, clicking the rotate button once it is above the schematic to orient it. Hit escape to stop adding inductors. Right click the L to change the inductor value. Save the schematic.

With L = 3.3mH and C = 0.1µF the resonant frequency is about 8.8kHz. A frequency response plot two decades either side of this is appropriate here (100Hz to 1MHz). Since we expect a sharp peak we will use more data points than previously (500). Do `Simulation > Edit simulation cmd` and enter the settings as shown in Fig.12.

The frequency response is show in Fig.13 (phase plot off). Right click the left (gain magnitude) axis and select Linear. The result is shown in Fig.14. Here we are unable to see the fact that the circuit is a low-pass filter because the peak dominates the plot. This illustrates the usefulness of using decibel plots. Linear axes, however, are often more appropriate for plotting smaller ranges.

Return to the dB plot and rerun the simulation with different values for number of points per decade in the Simulation Command settings (Fig.12). For example, try 20 and 2000 points per decade. Note the wide variation in peak height. This is due to the ideal, or close-to-ideal circuit being simulated – the idealised peak is very high and very narrow, so using more data points means it is more likely that one of the data points will be close to the true centre of the peak (resonate frequency), giving a very high value.

The simulation is not very realistic because the circuit being simulated has zero, or very low resistance. A real inductor and capacitor will have some series resistance, as will the input voltage source and wiring. The largest contribution in this case is likely to

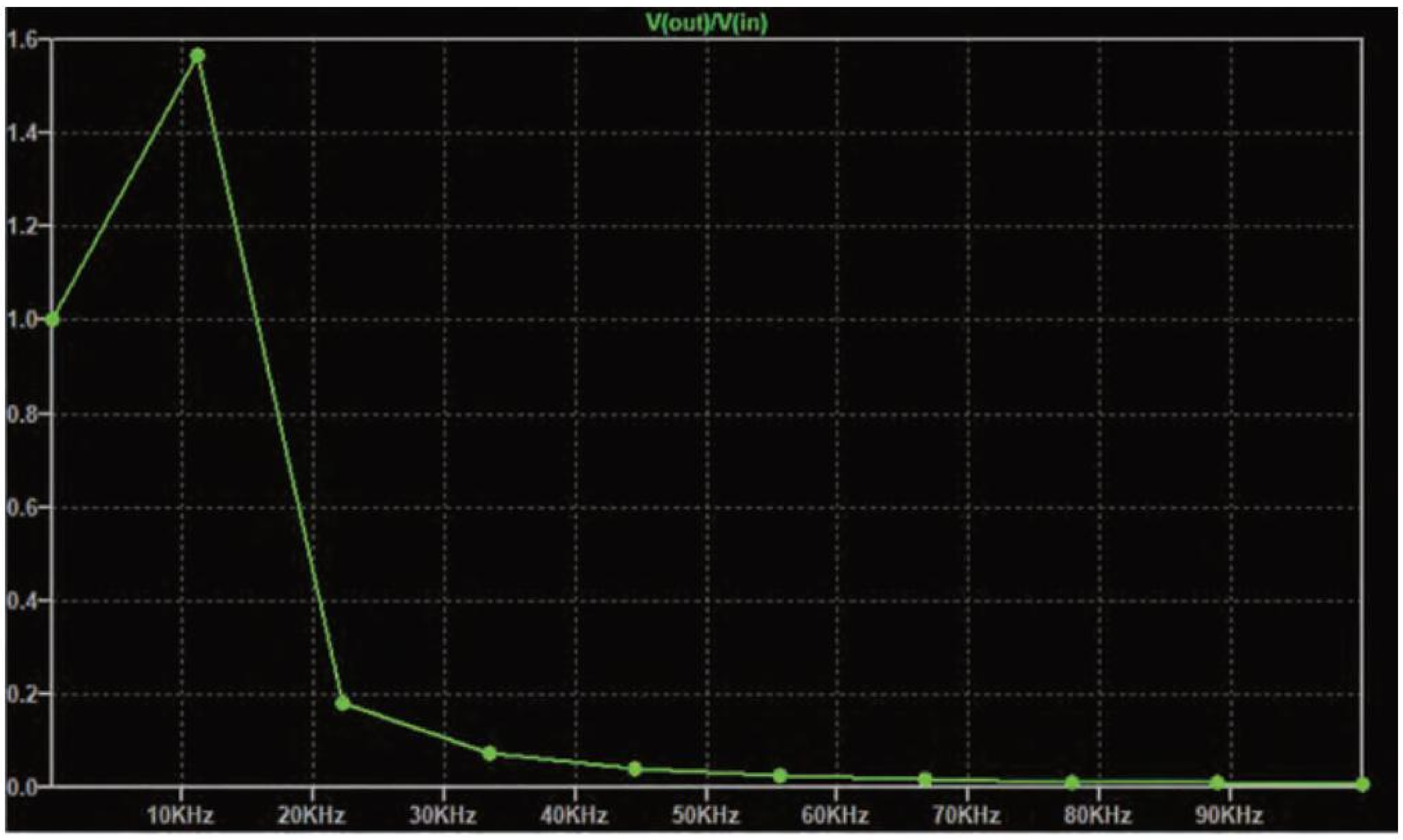


Fig.16. Poor choice of simulation and display setup produces a poor representation of the circuit's response.

be from the inductor. If we know the specific components being used we may be able to obtain series resistance values from the manufacturer's datasheet, or we can use estimated values. Wiring resistance can be calculated for specific situations, such as PCB layouts using a PCB trace resistance calculator, like the one available on **EEWeb.com**

The parasitic resistance of wiring or components can be included in the simulation by adding a suitable resistor to the circuit. Alternatively, for components such as inductors, these properties can be set directly. For example, right click on the inductor symbol to open the properties dialog and enter a value of 10Ω for the series resistance (see Fig.15). Similarly, set a value of 0.1Ω for the capacitor series resistance. Resimulate the circuit, with a variety of data point settings – notice the peak is less sharp, lower, and remains much more consistent as you vary the number of data points. The simulation is more realistic, but does not represent specific real components. However, note the Select Inductor button on the dialog in Fig.15, which does allow selection of specific components – if they are in the LTspice library.

Finally, for this month, go back to the Edit Simulation Command dialog and set up a linear sweep, with 10 data points, over a frequency range of 100Hz to 100kHz. Rerun the simulation and set both the frequency and magnitude axes to linear. There are very few data points so it is a good idea to mark them on the plot – right click in the waveform background and do `View > Mark Data Points`. The results of this simulation are shown in Fig.16. Note how this choice of simulation command and display options provides a very poor representation of the circuit's response – it is just about possible to infer a low-pass characteristic with a peak, but the peak appears to be above 10kHz – a long way from the actual value around 8.8kHz. Poor choices can provide poor results, but this is not just an issue with simulation – for example, one could make measurements of a real circuit and also get misleading results with a poor choice of data points.

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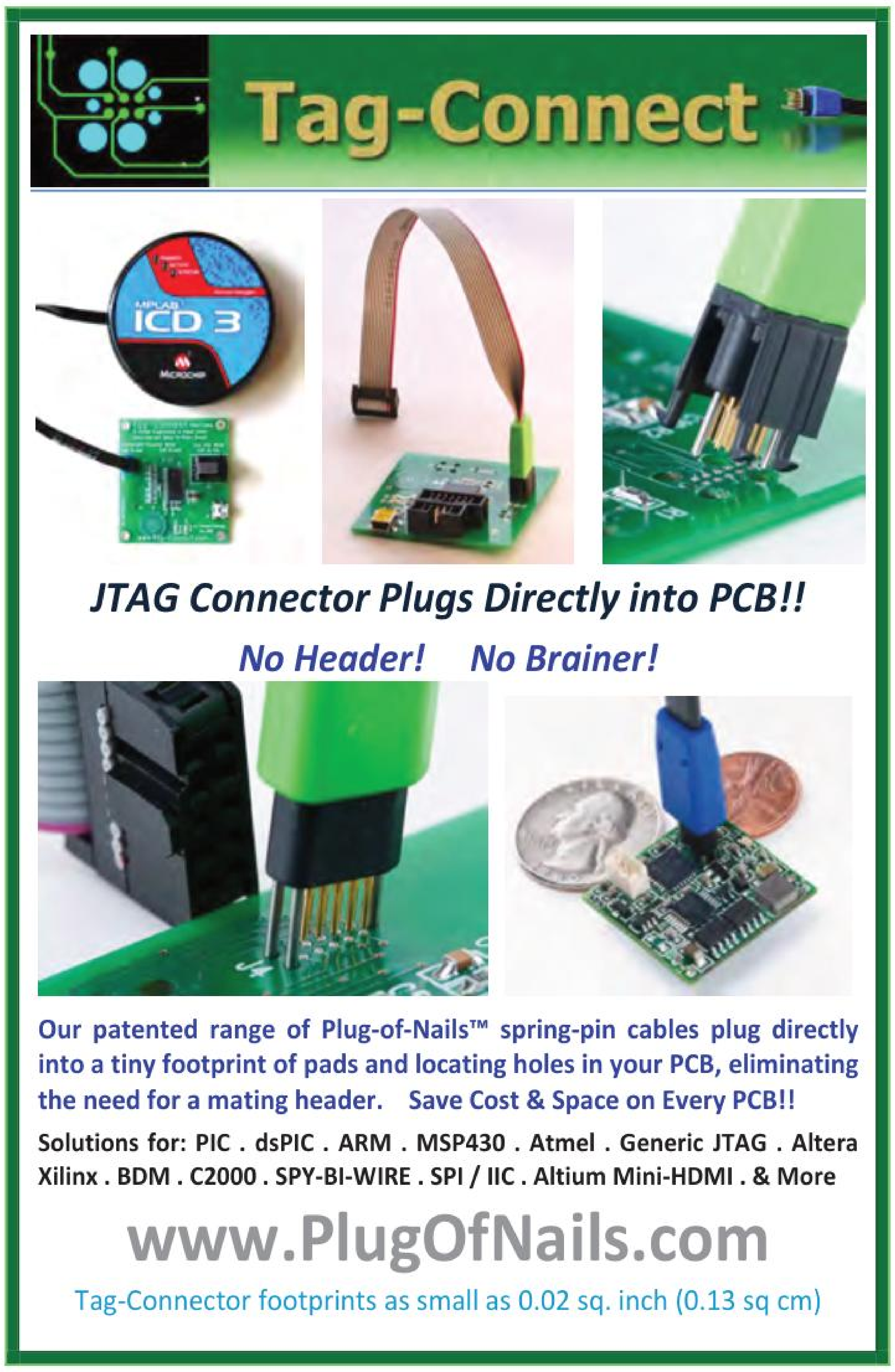
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The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

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AUDIO OUT

By Jake Rothman

GULP amplifier-speaker combo – Part 1

Over the last few months we've produced an ultra-low-power-consumption analogue synthesiser. Now we'll develop an amplifier and speaker for it – the *General Ultra Low Power* (*GULP*) amplifier-speaker. The requirements for battery-operated musical instruments are very different from mains-powered Hi-Fi. It would not be a good idea to use an amplifier with a quiescent current of 100mA and a low-colouration, inefficient loudspeaker, since the battery would be flat in half an hour. So, there's no point in getting the amplifier circuit right until the correct loudspeaker is selected. The amplifier, speaker and enclosure constitute an electroacoustic system that has to be designed as a whole. In electric guitar parlance this is often called a 'combo'.

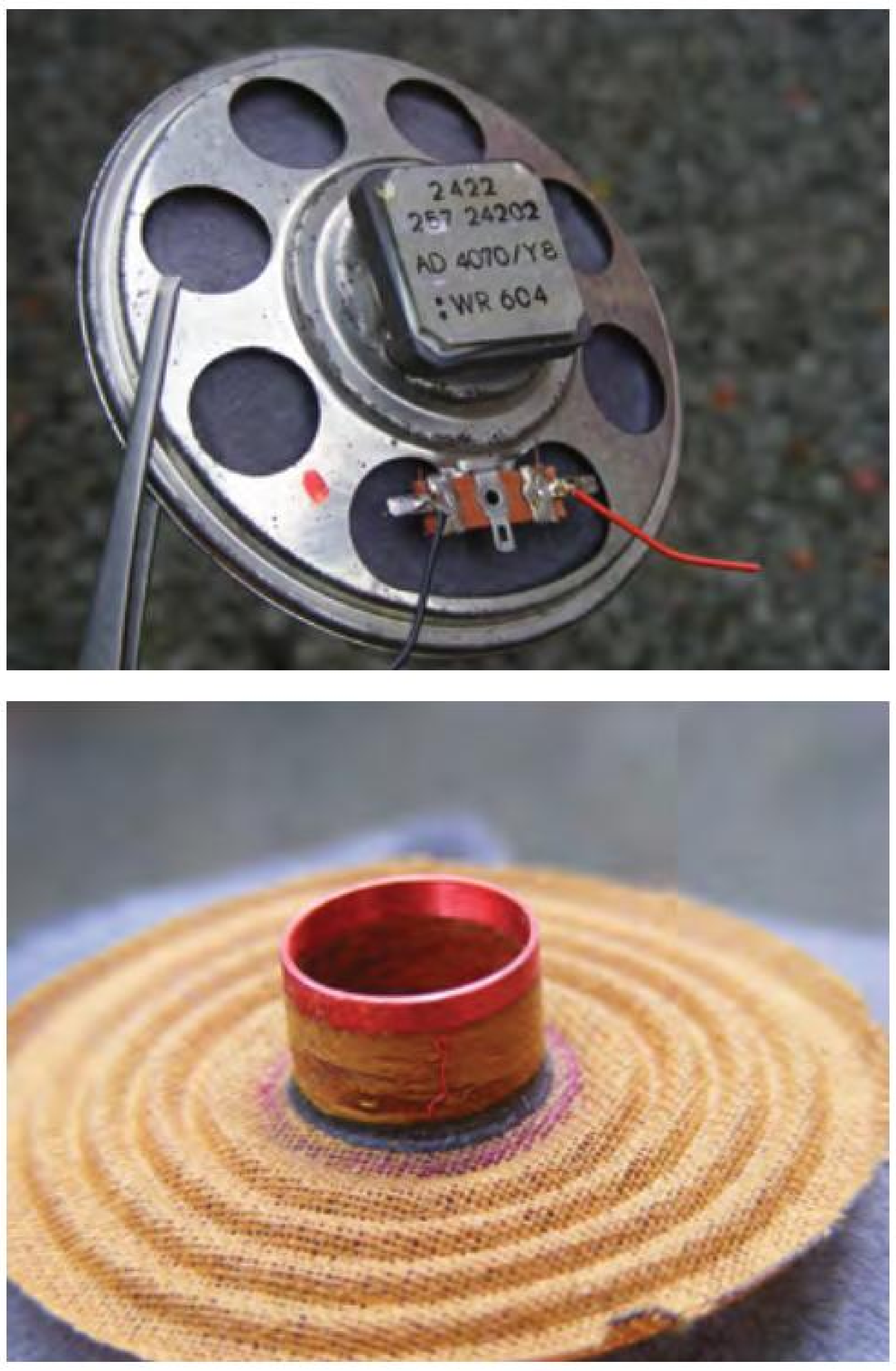


Fig.2. Philips AD4070 4-inch driver with ultra-light voice coil. It is no longer made, so snap it up if you see one on eBay.

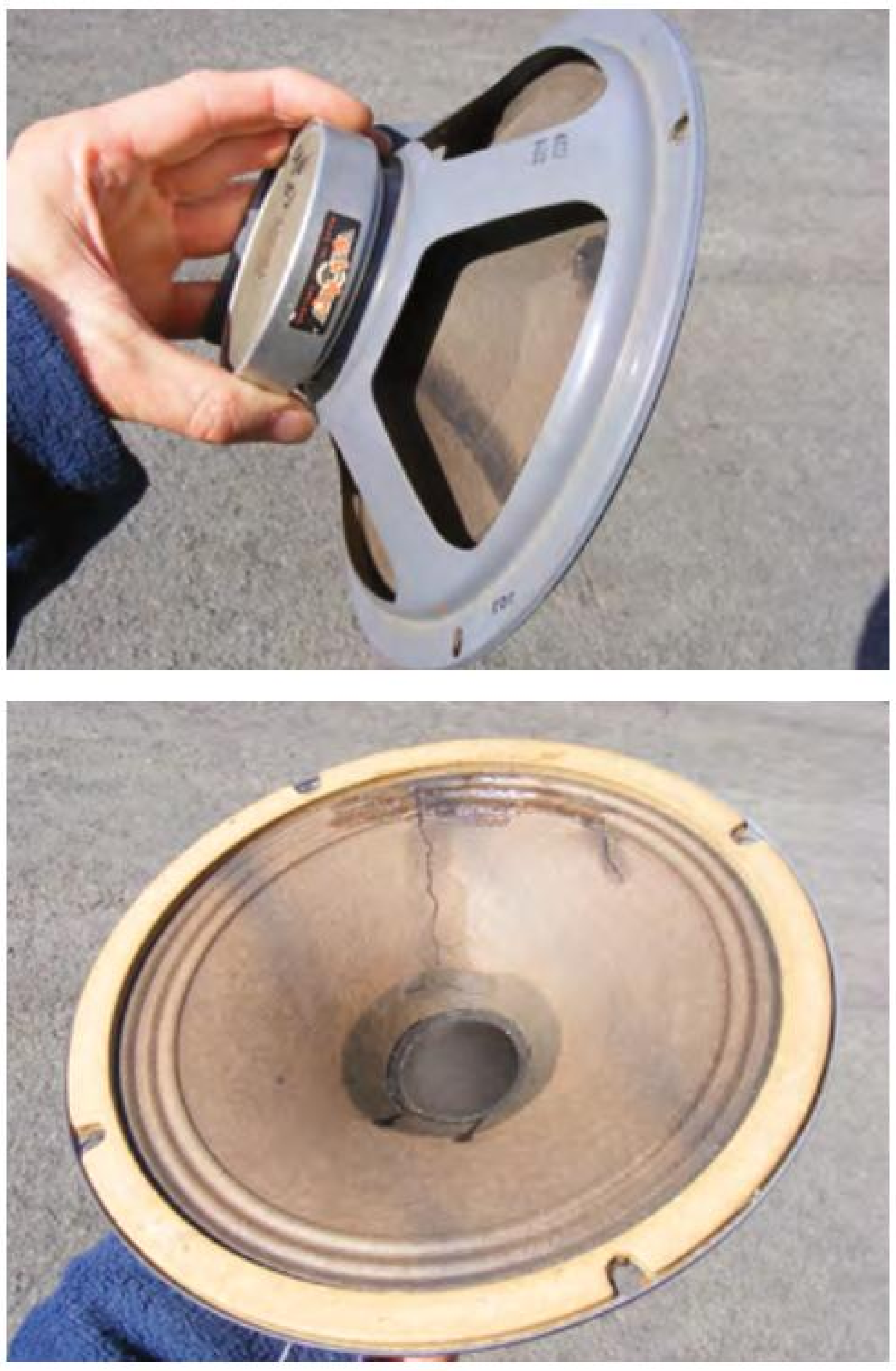


Fig.3. (top) An old 8-inch radio loudspeaker, such as this Elac unit is ideal for this combo design; (b) the ripped diaphragm that I repaired using PVA glue on the cone and rubber solution on the surround.

Loudspeaker selection in the GULP combo amplifier

It is unnecessary to have high power output in portable instruments because you're usually close to the speaker when playing and benefiting from the inverse-square law, especially for practising and 'knob twiddling'. For an audience, the amplifier would normally be plugged into a powerful external amplifier or PA (public address) system. Also, efficient speaker drive units normally have lightweight and short voice-coils wound on paper formers. Along with the delicate paper cones needed for efficient propagation, these factors limit power handling to around a few watts. If a loudspeaker is rated at 50W, it will be so inefficient it will be impossible to hear if a 100mW signal is fed to it.

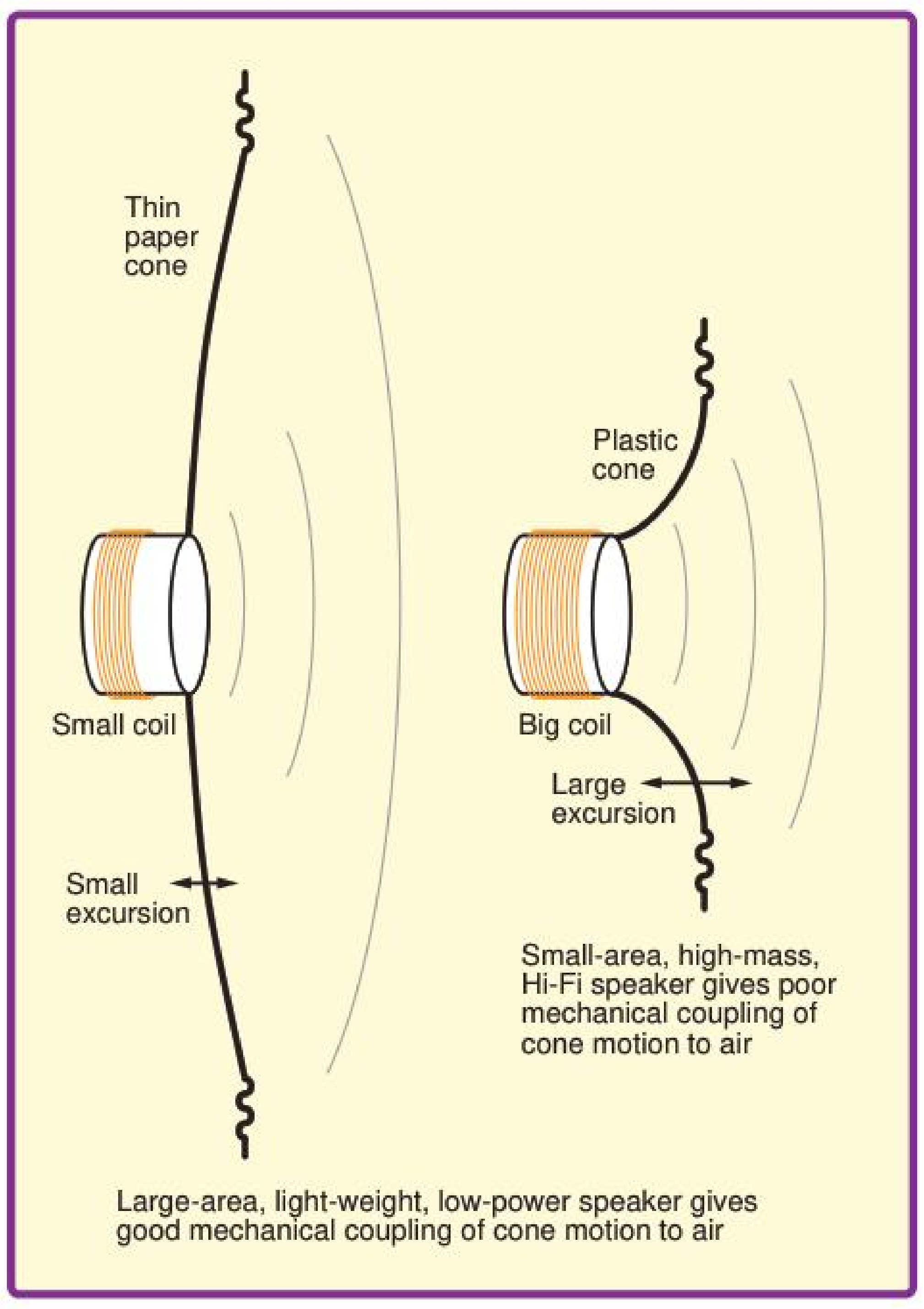

Thin paper cone
Plastic cone
Small coil
Big coil
Large excursion
Small excursion
Small-area, high-mass, Hi-Fi speaker gives poor mechanical coupling of cone motion to air
Large-area, light-weight, low-power speaker gives good mechanical coupling of cone motion to air

Fig.1. A large lightweight cone converts more electrical energy to acoustic energy due to better mechanical impedance matching.

Another factor is the size of the loudspeaker; surprisingly, a small speaker needs more power than a big one. A large-area lightweight cone will couple mechanical motion to the air more effectively. This is called 'acoustic impedance matching' (see Fig.1) and it is just as important as electrical impedance matching to get maximum power transfer.

A small heavy plastic cone has a bad impedance match to light-weight 'floppy' air. Circular cones are louder than elliptical designs because they couple better and have more prominent cone resonances. Ideally, a cone of 5 to 8-inches is the minimum. In the market place small size is very important, so 2-inch speakers are often used, which is a severe compromise, but this constraint doesn't apply to home constructors. Another problem with small speakers is the resonant frequency (f_S). Since the cone is fixed at the edge of the frame, a small diaphragm assembly is going to be much stiffer, and just like any spring-mass system, it's resonant frequency is going to be higher, typically 400Hz. This spoils the sound, since below this frequency the speaker acts as a high-pass filter, losing much of the bass below f_s. A maximum f_s of 220Hz is acceptable; but 100Hz is ideal. Getting

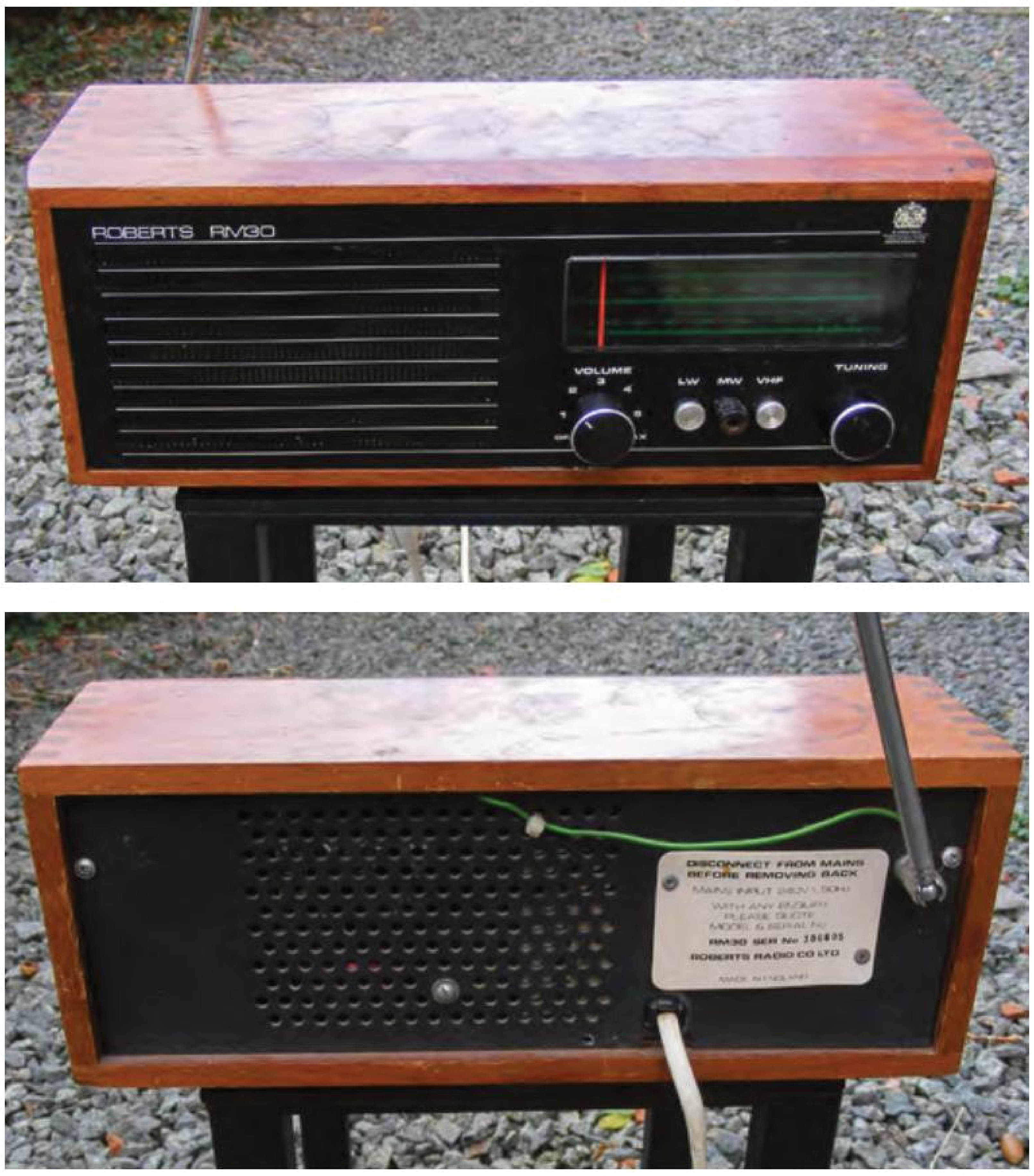
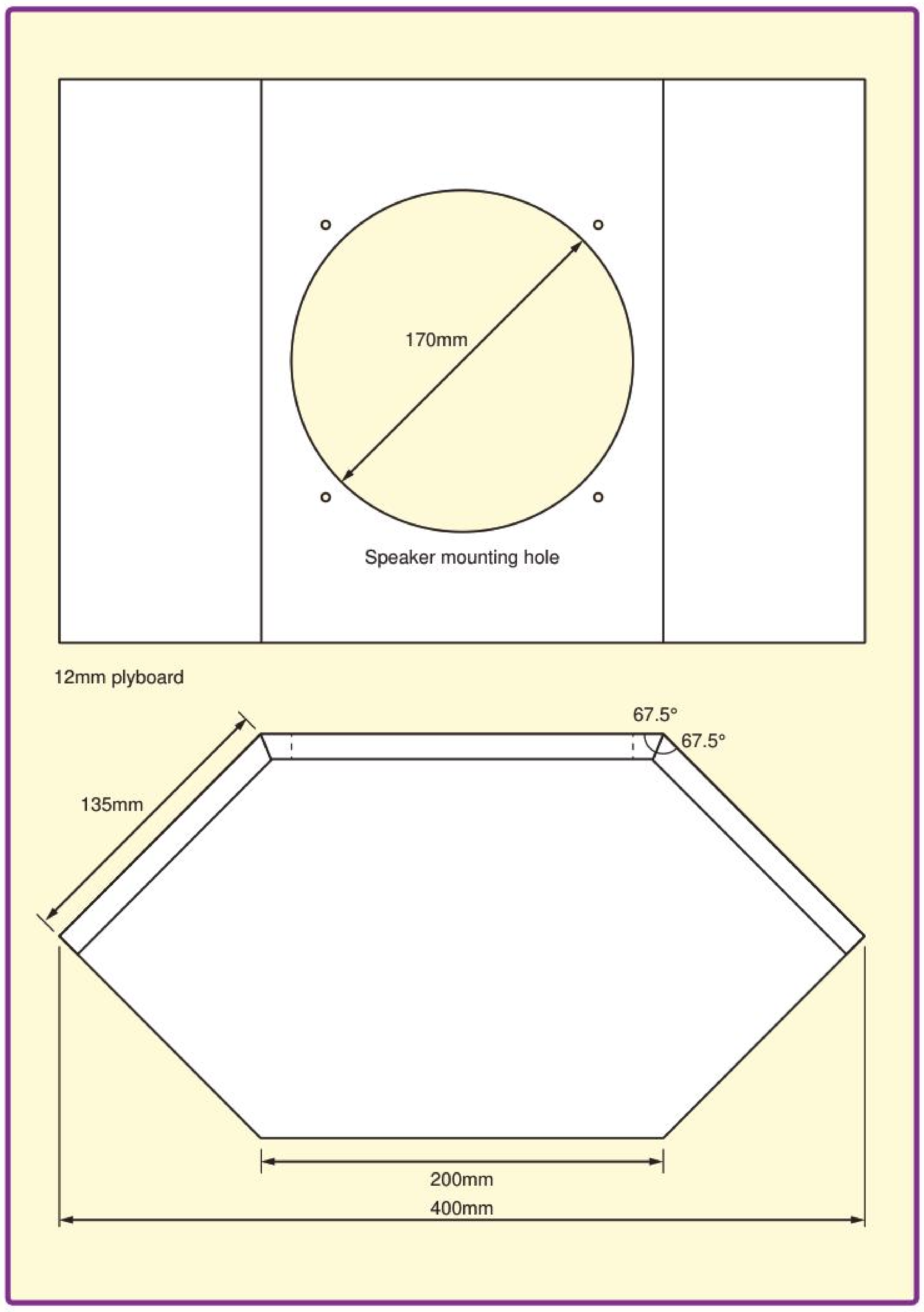


Fig.4. (Above) This old Roberts radio has a classic open-back cabinet, which is essential for stopping an internal air spring developing in the box, which would raise the resonant frequency.

Fig.5 (Right) A suitable cabinet for the synthesiser speaker. This is based on an old Wharfedale wall-mount speaker.



a value of f_S lower than this is difficult, since it usually entails reducing stiffness by putting rubber surrounds onto the cone edge, which then adds mass, reducing efficiency.

Suitable loudspeakers are now getting hard to find because in today's world of lithium batteries, efficiency is not regarded as important. One unit I found to be good is the Celestion 15W 8-inch guitar unit called the 'Eight 15'. This is available from Lean Business (**www.lean-business.co.uk**). One 4-inch driver I've been using for years in my Elysian Theremin design (**http://theremin.co.uk**) is the Philips AD4070 (Fig.2). It has the smallest, lightest voice coil I've seen, having no former . Unfortunately, it is not made any more (but I do have 100 in stock if anyone would like to buy one). Fig.3 shows the best speaker I have found, a 15Ω 8-inch unit made by Elac, 8RM/239. It is rated at 5W and makes a huge sound with only 200mW. It had a ripped cone, which I repaired with PVA glue. Unfortunately, it's another superb vintage component that is no longer made, so grab one if you see it on eBay or a junk shop – I found mine in a skip! An Elac unit was part of the famous Brian May Deacy amp. When it was recreated, Celestion had to make 40 different speakers until they succeeded in emulating it. The tooling costs must have been huge.

Cabinet

Compared to a combo practice amp, normal Hi-Fi systems are more concerned with extending deep bass response and have sealed or reflex cabinets. If we put a lightweight high-efficiency driver into such a cabinet, the compression of the air by the cone inside the cabinet will push the resonant frequency of the driver too high, giving a horrid 'boxy' sound. To avoid this, the cabinet in low-power systems, such as portable radios, is usually of the open-back design, like the Roberts radio shown in Fig.4. This type of cabinet does not raise the resonant frequency but it does suffer from anti-phase cancellation. This is because the front wave cancels with the back wave, attenuating the bass, which contains the longer wavelengths. The effect of this becomes more apparent as you move away from the cabinet. However, if you are right in front of the speaker the effect is much less noticeable. With open-back cabinets the basic rule is the bigger the better, since the path length from front to back increases. There is no critical internal volume or tuning to contend with, unlike Hi-Fi speakers.

Another aspect of open-back design is that high electromagnetic damping of the cone is not needed, as opposed to normal Hi-Fi speakers, where it is desirable. Some designers have said that a total combined amplifier-driver Q of 4 is the optimum, unlike the Butterworth 0.7 or Bessell alignments used for Hi-Fi speakers. This makes the engineering simpler and cheaper; we don't need big expensive magnets. The loudspeaker can be included in the negative feedback path around the amplifier to raise the output impedance and reduce damping. A current-sensing resistor in series with the speaker is normally employed. A suitable cabinet is shown in Fig.5, and the finished result in Fig.6. A final point on speakers; delicate paper cones need a grille to protect them from being torn. Make sure the grill is of open weave and spaced to prevent rattling and attenuation – see Fig.7.

Amplifier selection

In a production environment, an amplifier chip is normally selected to reduce assembly costs compared to a discrete component design. Interestingly, there are lots of acoustic gaps (silent sections) when playing simple musical instruments. This means the current consumption of the amplifier when it is doing nothing is more important than when it is going flat out. Thus, a class AB design is optimum, having very low quiescent current (I_q) with an efficiency of around 70% when delivering full power. The low-power class D (pulse-width modulation)

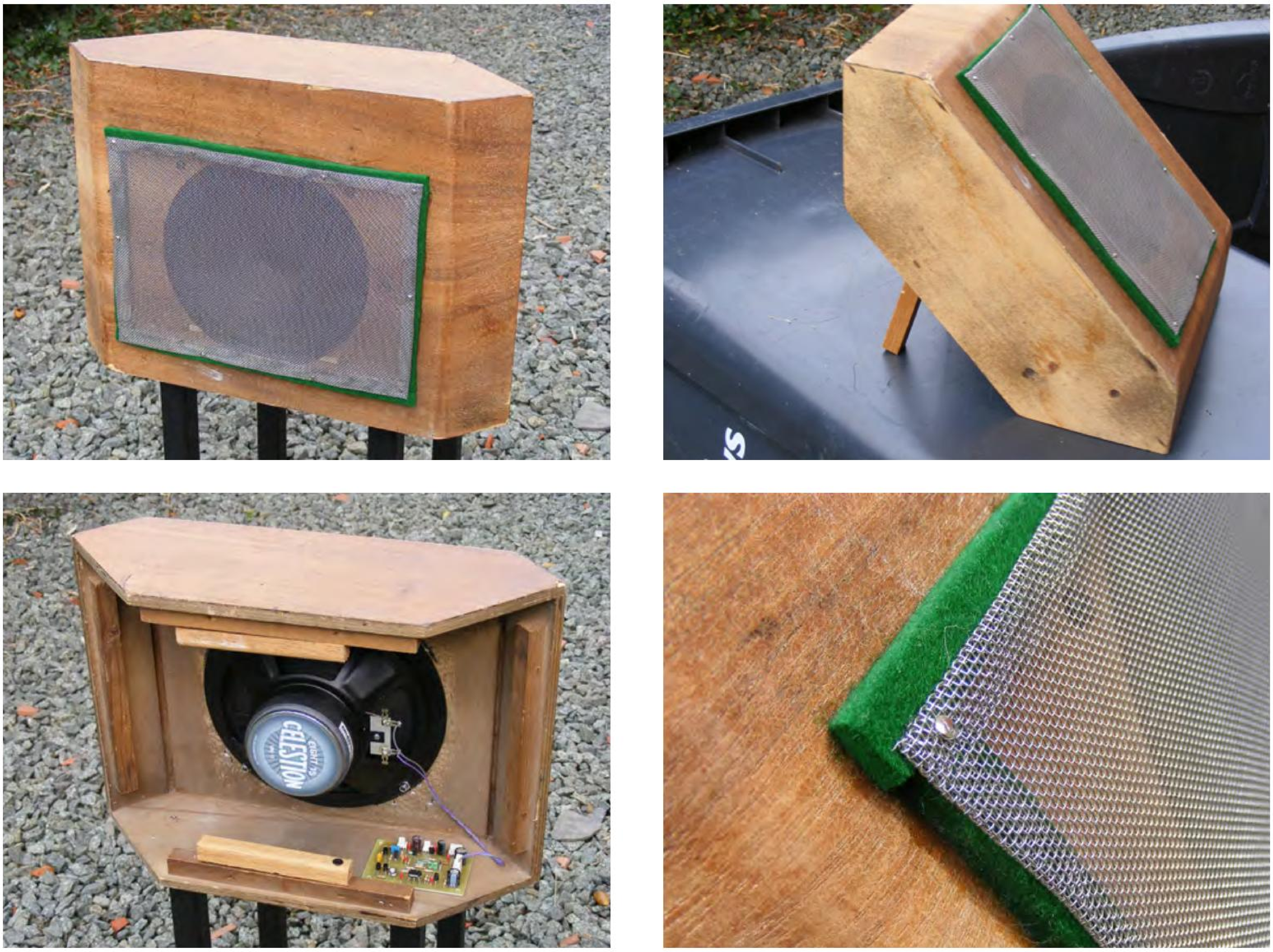


Fig.6. The finished result – designed to be effective rather than pretty!

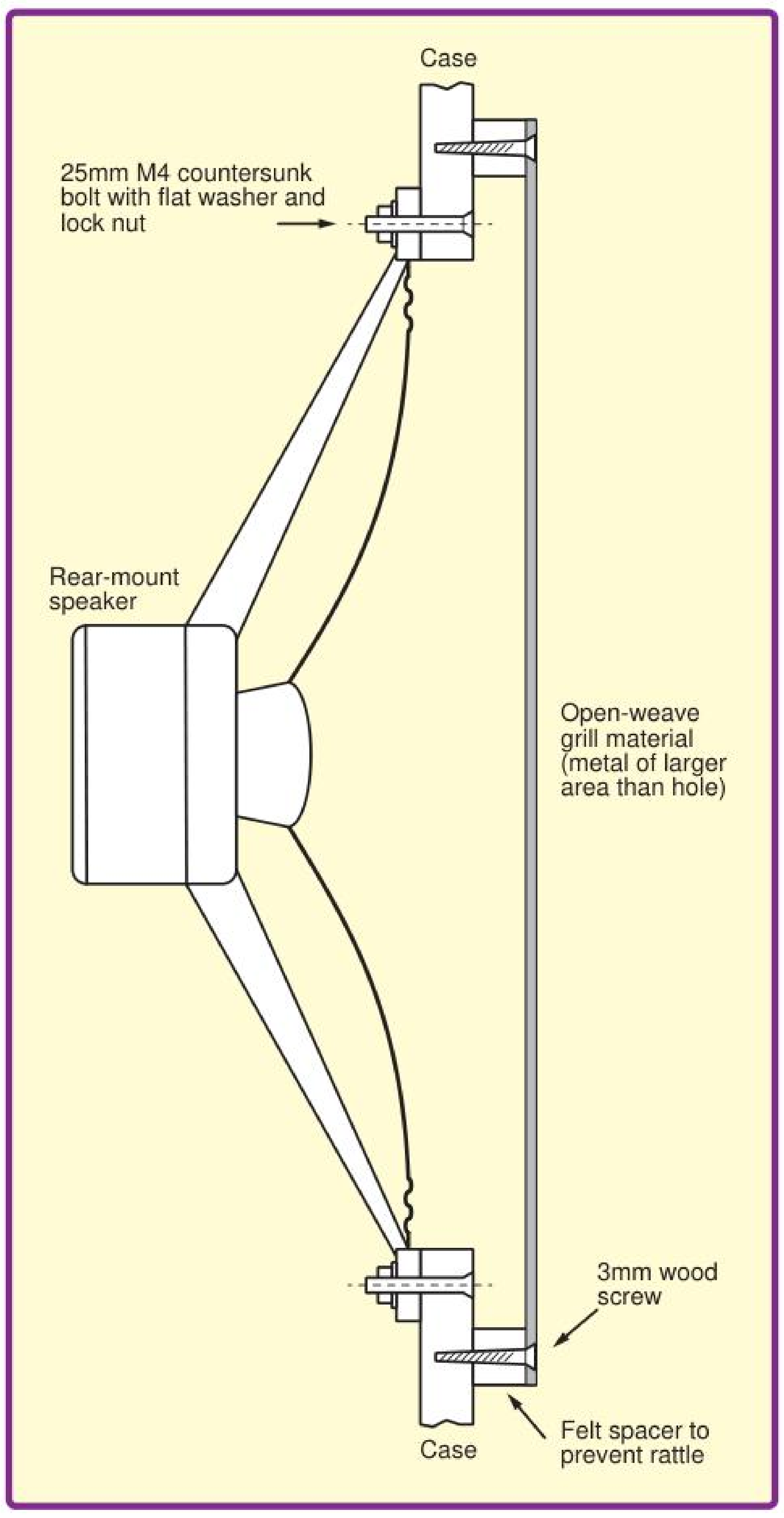

Case
25mm M4 countersunk bolt with flat washer and lock nut
Rear-mount speaker
Open-weave grill material (metal of larger area than hole)
3mm wood screw
Felt spacer to prevent rattle
Case

Fig.7. It's essential the grille arrangement does not result in acoustic attenuation or annoying buzzes.

designs, such as the PAM8302A, usually have 93% efficiency at full power, but at the expense of a higher I_q, typically 7-10mA. The most popular class AB chips are the LM386 and the TBA820. Although these designs are decades old, they are still the best for the job. I used an LM386 in the Gen X-1 because it has an I_q of typically 4mA and an output of 250mW. For a large FM radio design, I used the TBA820 to get double the power with around 6mA I_q. Another chip with low I_q is the bridged NJM2073, which doesn't need an output electrolytic capacitor. The Texas TPA6112 headphone amplifier looks interesting, having very low I_q, but it is still rather 'expensive' (around £1.50). I did notice a Chinese copy module on eBay, but a Chinese holiday got in the way of purchasing it! Some example chip circuits are shown in Fig.8 and Fig.9, and these can all be used for the synthesiser if you want. However, If a discrete circuit is used, the I_q can be reduced by more than half because it can be optimised by trimming. This is not cost-effective for commercial production, but for somebody building their own, it's a very sensible battery-preserving approach.

Discrete amplifiers

Normally, a designer takes great care to minimise crossover distortion in a class-AB amplifier. With typical Hi-Fi common-emitter output amplifiers, if the I_q is reduced from an optimum of 6-50mA, the crossover distortion

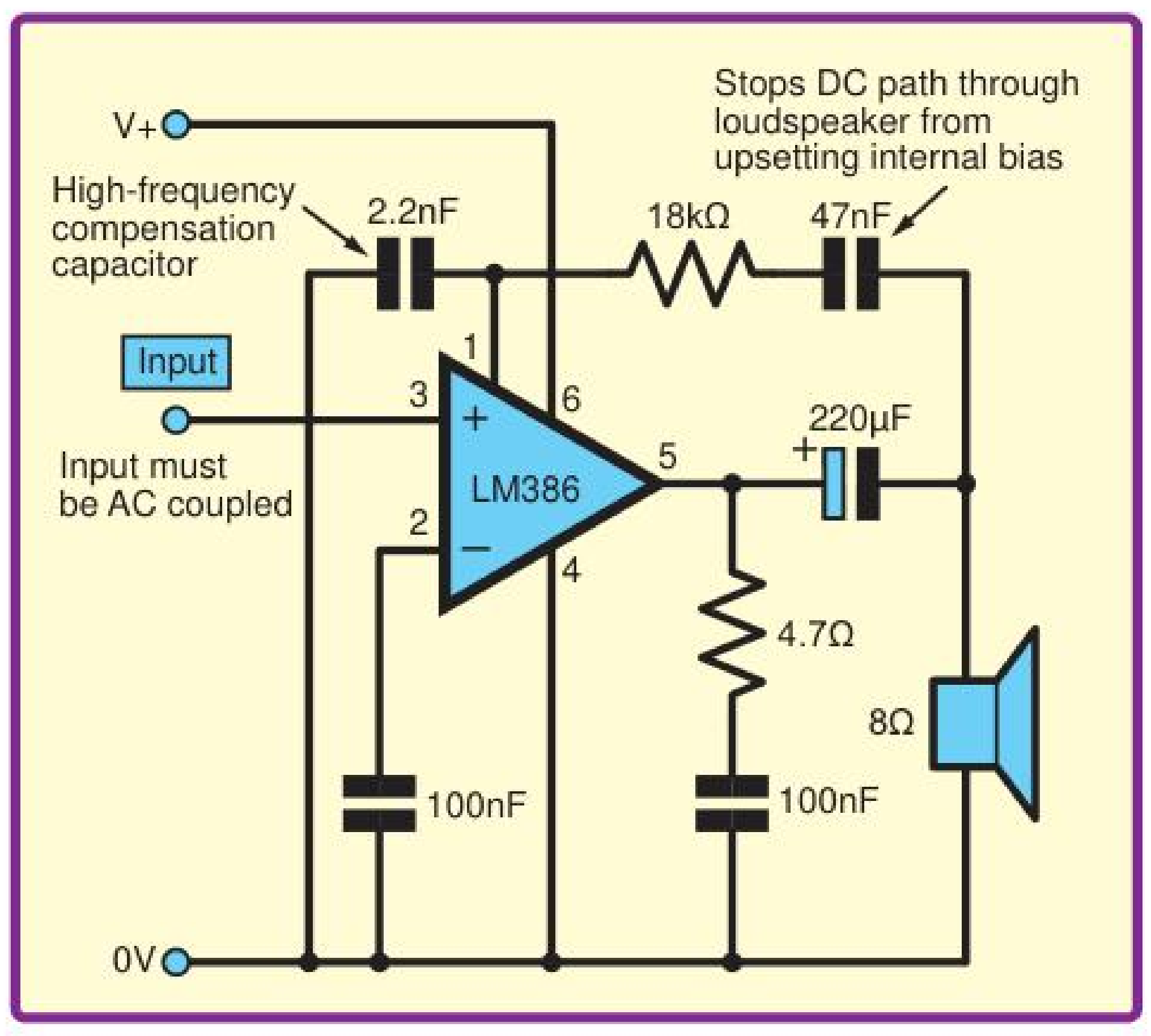

V+
High-frequency compensation capacitor
2.2nF
Stops DC path through loudspeaker from upsetting internal bias
18kΩ
47nF
Input
Input must be AC coupled
1
3
6
+
LM386
5
2
−
4
220µF
+
4.7Ω
8Ω
100nF
100nF
0V

Fig.8. LM386 circuit suitable for a synthesiser. It normally has too much gain for high output synthesisers, since it was designed for radios; I have fixed this by adding extra negative feedback. This normally causes high-frequency instability, hence the 2.2nF capacitor which reduces the negative feedback at high frequencies. In a standard (radio) configuration, a 0.3V input would give an output of 6V, a gain of 20. However, here the output is reduced to 3.5V, a gain of 11.

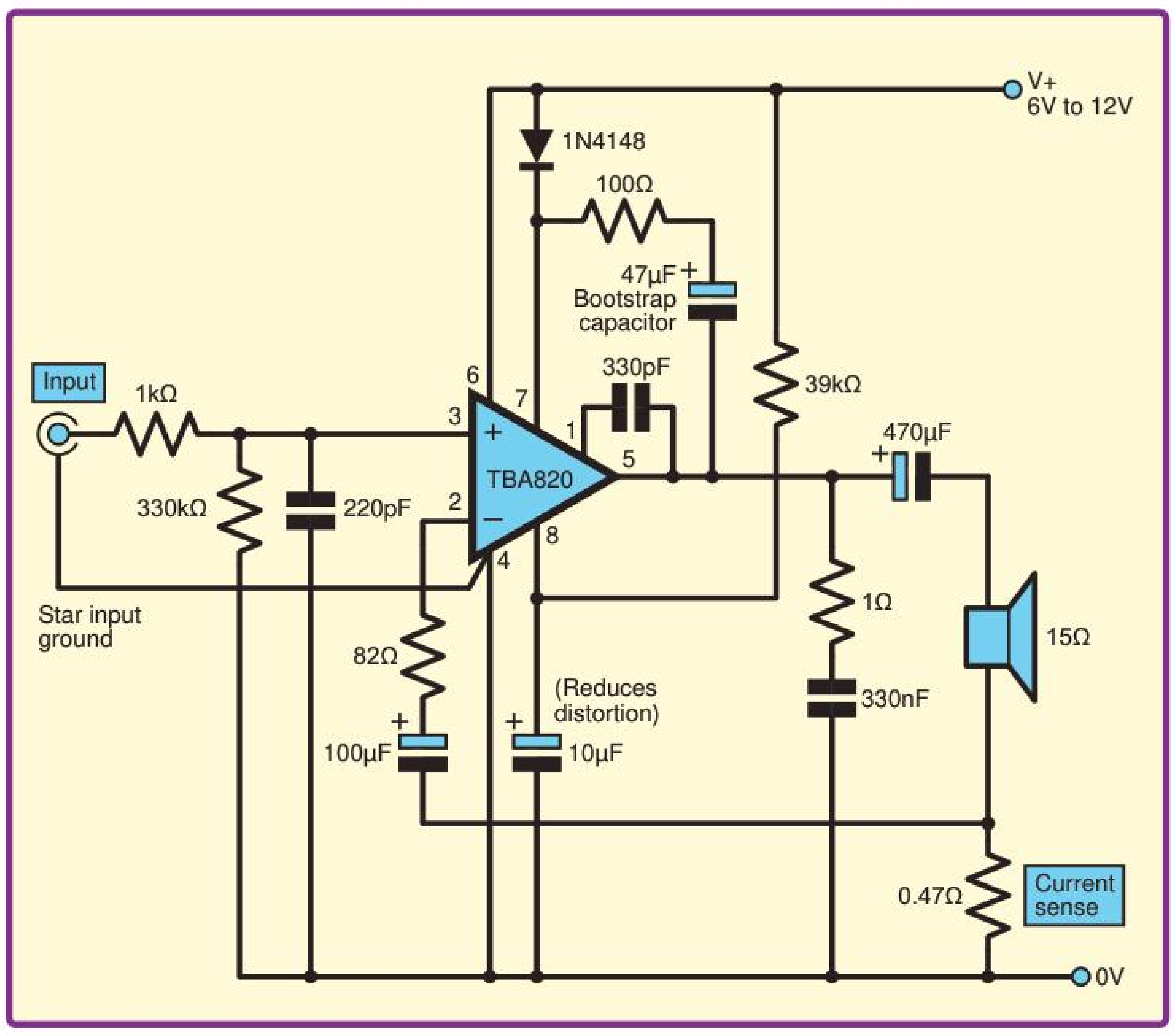

V+
6V to 12V
1N4148
100Ω
47µF
Bootstrap capacitor
330pF
39kΩ
Input
1kΩ
6
7
3
1
5
470µF
TBA820
330kΩ
220pF
2
8
4
Star input ground
1Ω
15Ω
82Ω
(Reduces distortion)
330nF
100µF
10µF
0.47Ω
Current sense
0V

Fig.9. For higher power, a TBA820 works well. This employs bootstrapping, using an electrolytic capacitor to boost output swing.

gets worse. It can be clearly heard on complex acoustic music, but on single electronic notes from an instrument, all distortions are less audible because there is nothing to intermodulate with. However, we clearly don't want gross distortion, since we might want to add delay effects, which would sound terrible with excessive distortion. In the circuit for this project's amplifier, detailed next month, it is possible to reduce the I_q to a sensible minimum of around 1.4mA, giving a total current consumption for the whole circuit of 2.2mA. This is adjusted with preset PR1. To check the crossover distortion it's best to do it at 20kHz on a scope, where the magnitude of the open-loop gain is reducing. If you don't have a scope then you can 'tune' this by ear at 300Hz. Low crossover distortion at 20kHz (shown in Fig.10) is not important here, so I_q can be reduced further if desired. Since the battery voltage is low, we also need to maximise voltage swing. Germanium output transistors and transformer coupling could also be used (Fig.11), but these components are rare and expensive now – do feel free to experiment, such (retro) circuits have become fashionable again. Reducing speaker impedance from the standard 8Ω to 4Ω is another trick, but this doubles current consumption. Also, I've found 4Ω speakers are less efficient compared to higher impedance versions of the same model, possibly because they are wound with thicker gauge wire.

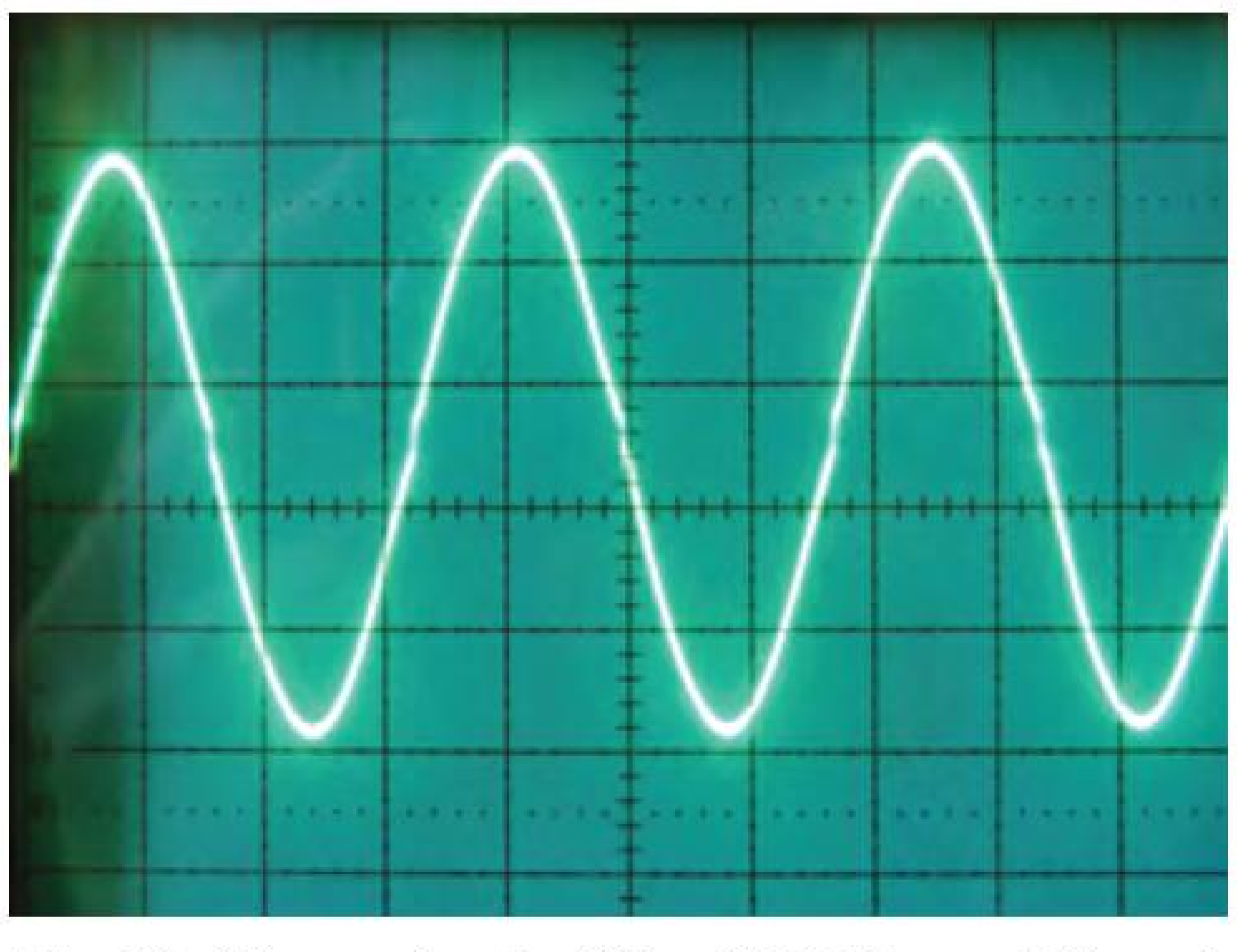


Fig.10. The output of the GULP amplifier at 20kHz with insufficient I_q. Note crossover distortion glitches.

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Next month

That's all for this month – next time, we will look at the circuit design and construction of the *GULP* amplifier.

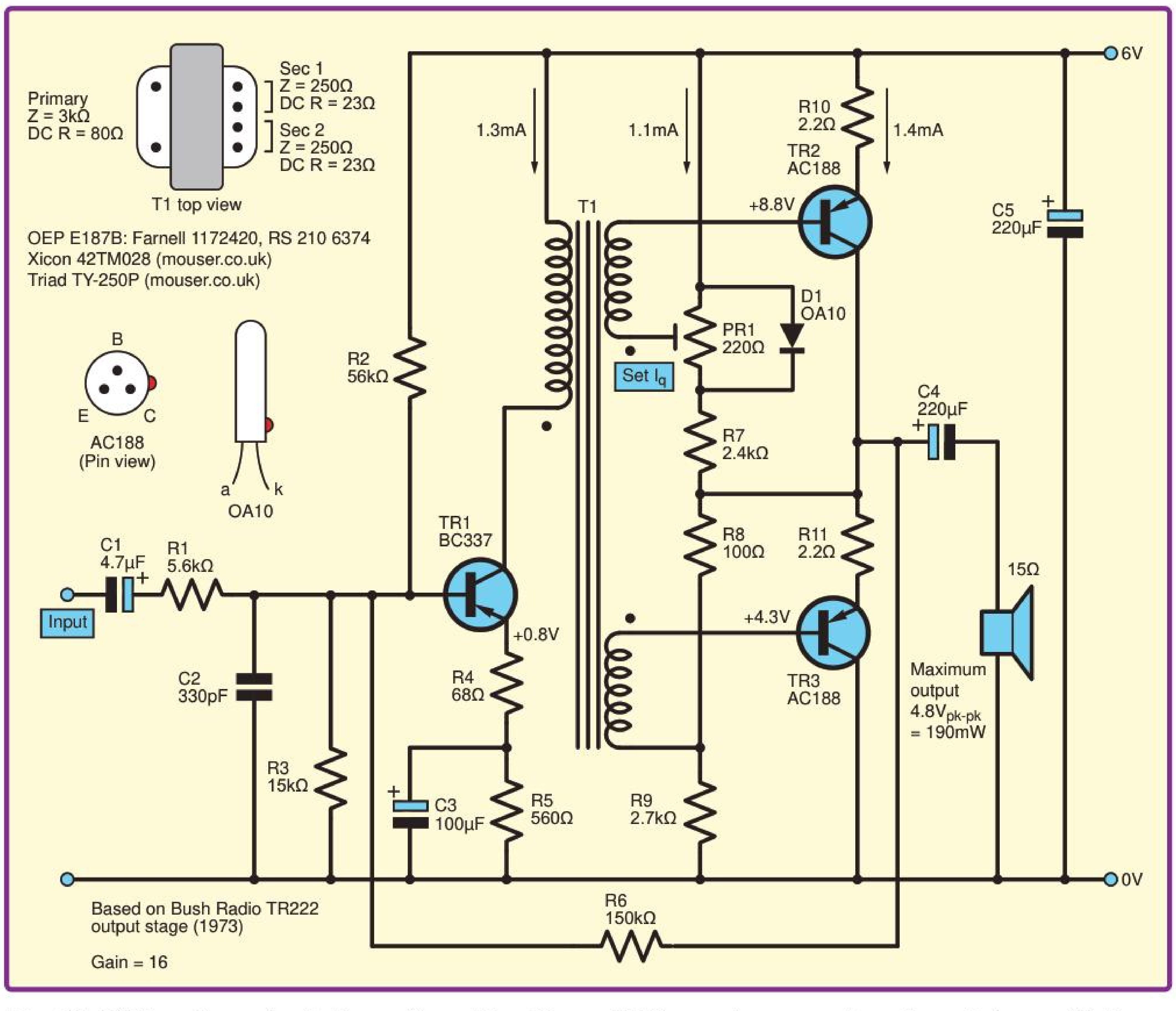
6V
Primary
Z = 3kΩ
DC R = 80Ω
Sec 1
Z = 250Ω
DC R = 23Ω
Sec 2
Z = 250Ω
DC R = 23Ω
T1 top view
OEP E187B: Farnell 1172420, RS 210 6374
Xicon 42TM028 (mouser.co.uk)
Triad TY-250P (mouser.co.uk)
1.3mA
1.1mA
R10
2.2Ω
1.4mA
TR2
AC188
T1
+8.8V
C5
220µF
D1
OA10
PR1
220Ω
Set I_q
B
E
C
AC188
(Pin view)
a
k
OA10
R2
56kΩ
R7
2.4kΩ
C4
220µF
TR1
BC337
R8
100Ω
R11
2.2Ω
C1
4.7µF
R1
5.6kΩ
Input
+0.8V
+4.3V
15Ω
C2
330pF
R4
68Ω
TR3
AC188
Maximum output
4.8V$_{pk-pk}$
= 190mW
R3
15kΩ
C3
100µF
R5
560Ω
R9
2.7kΩ
0V
Based on Bush Radio TR222 output stage (1973)
R6
150kΩ
Gain = 16

Fig.11. Old radio output stages from the 60s and 70s used germanium transistors with transformers. These often worked well with low-power batteries.

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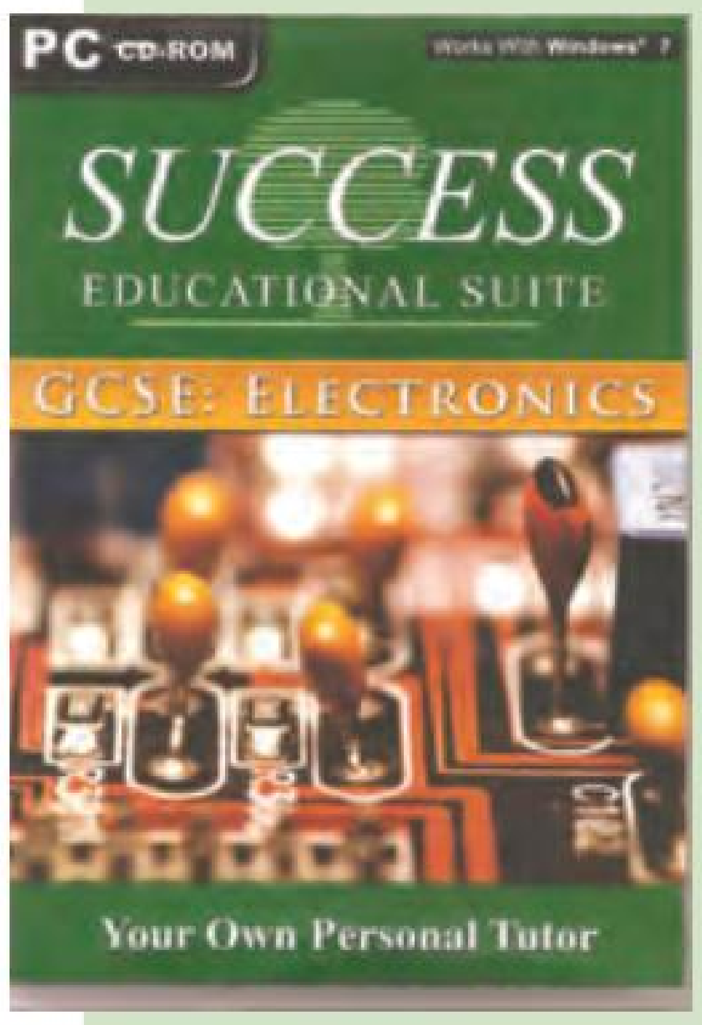

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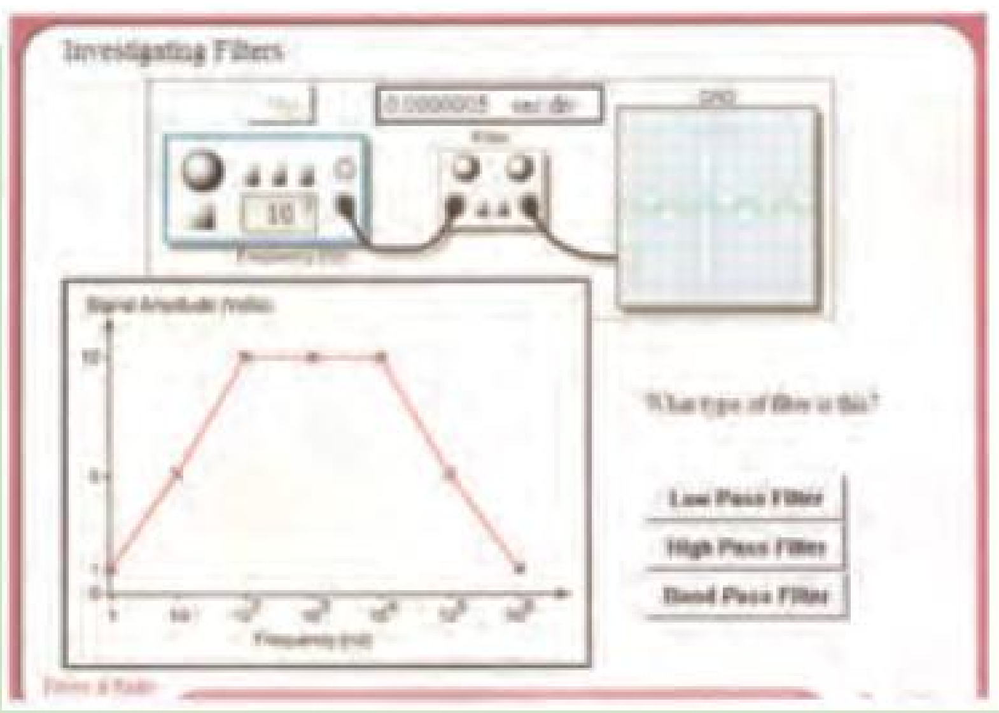

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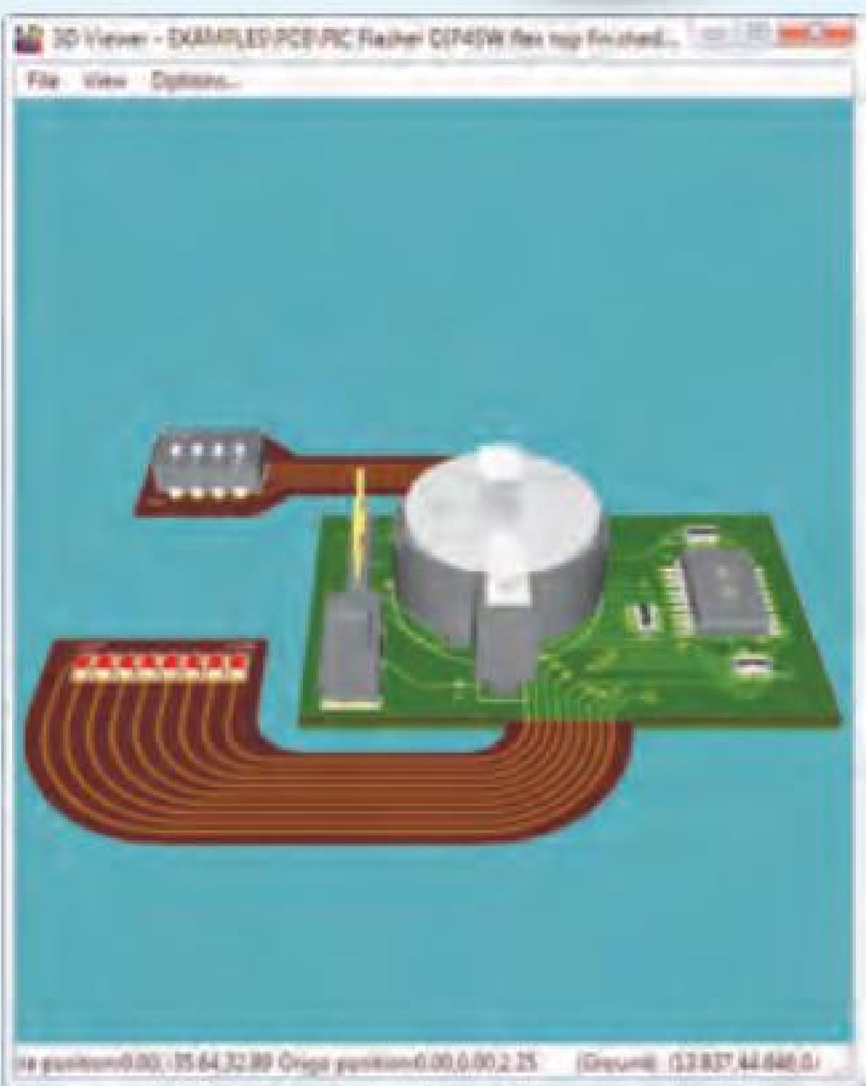

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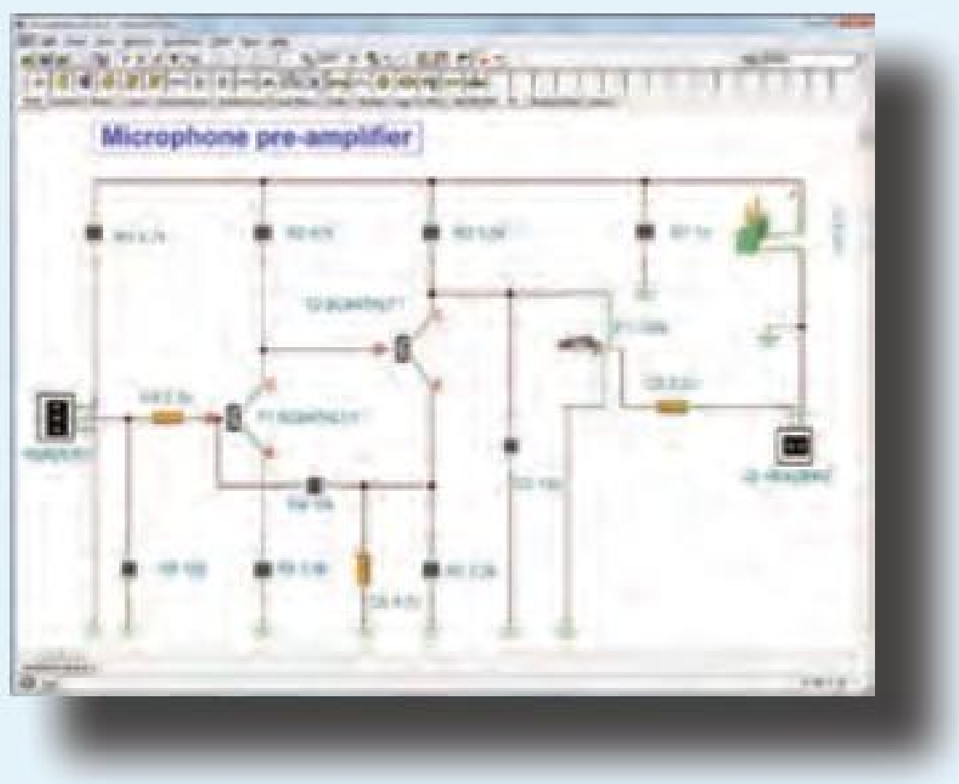

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ELECTRONICS TEACH-IN 2

ELECTRONICS TEACH-IN 2 CD-ROM
USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

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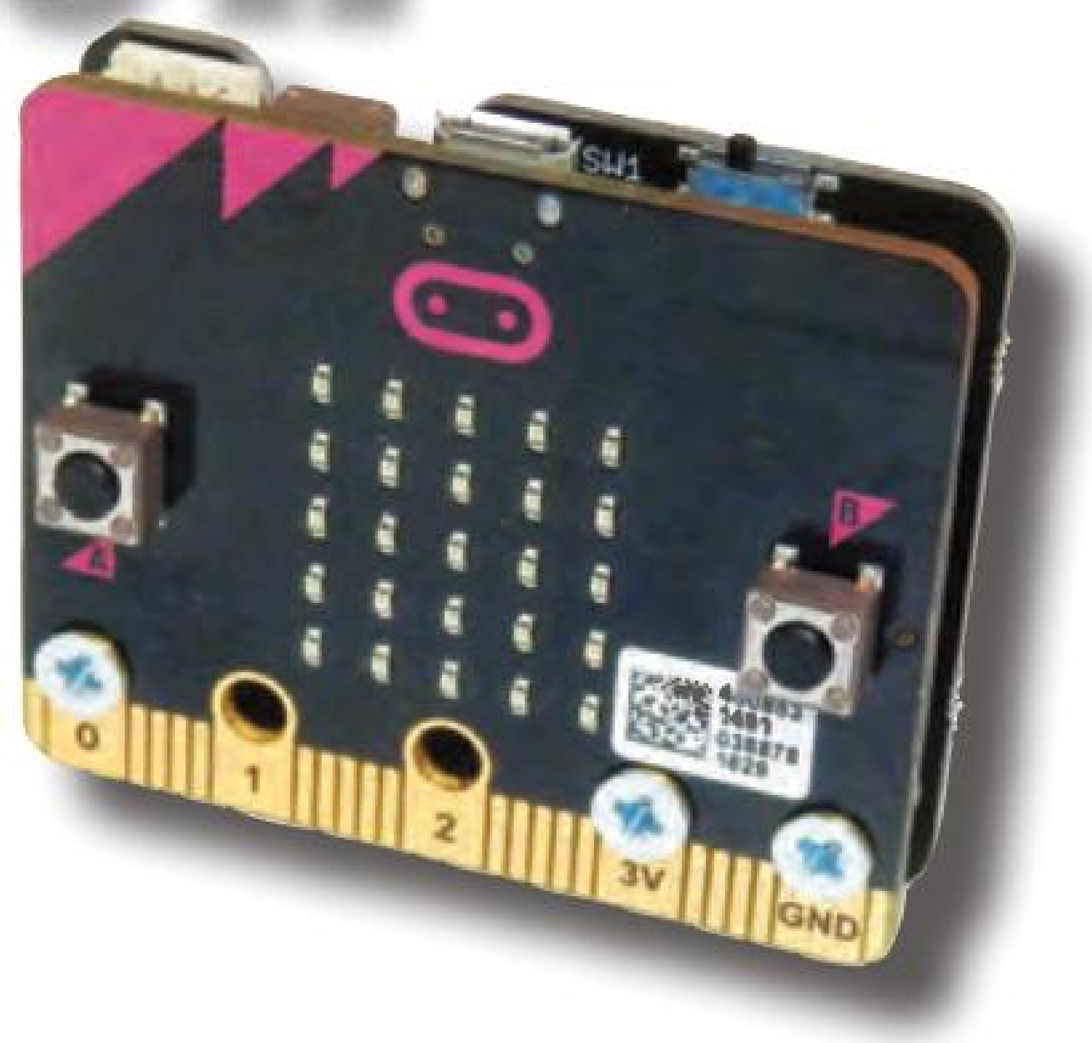

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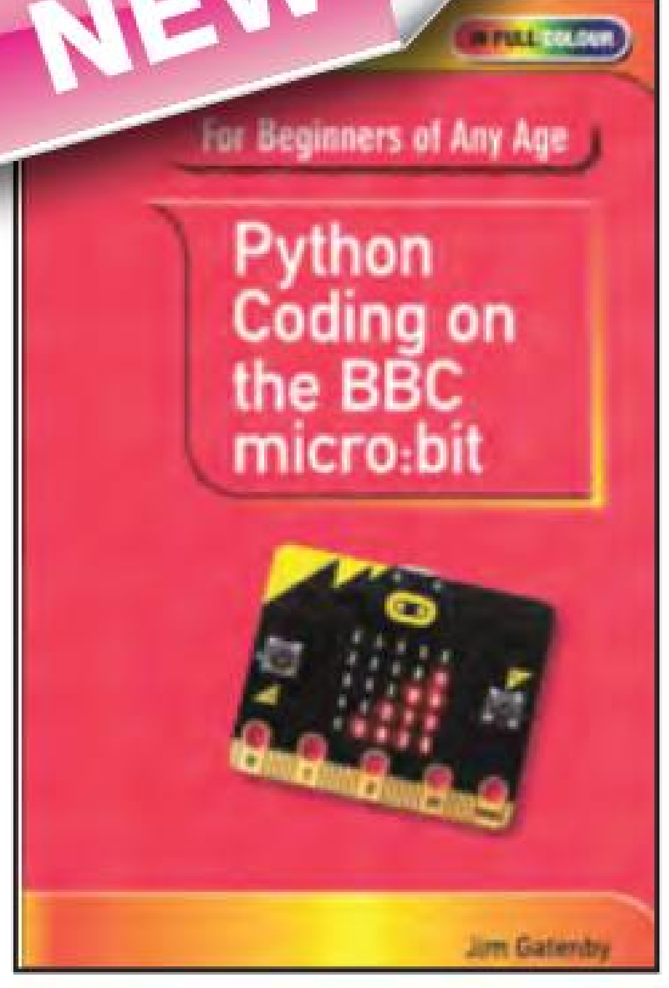

PYTHON CODING ON THE BBC MICRO:BIT
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

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This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** **£7.99**

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Mike Tooley

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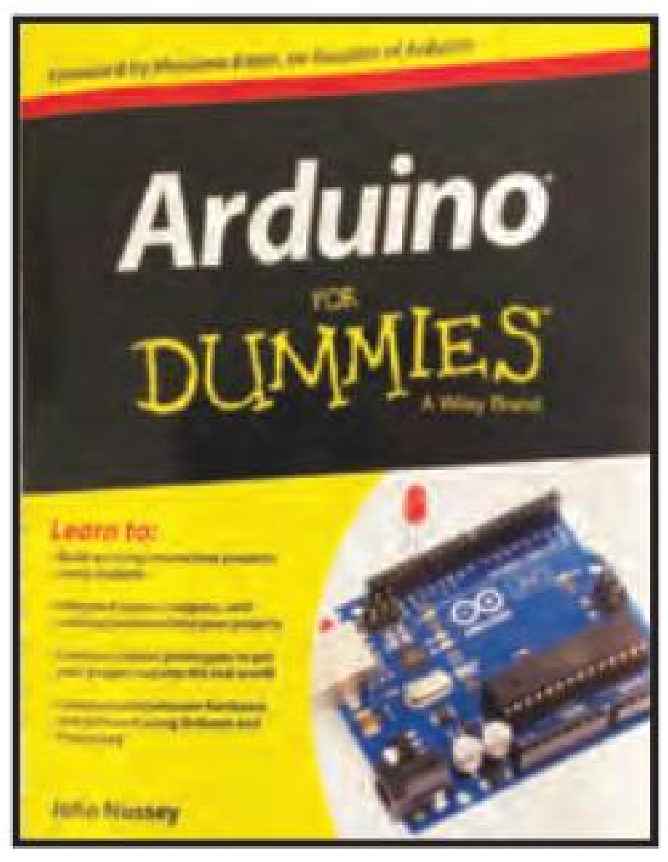
Teach-In 2016

Exploring the Arduino



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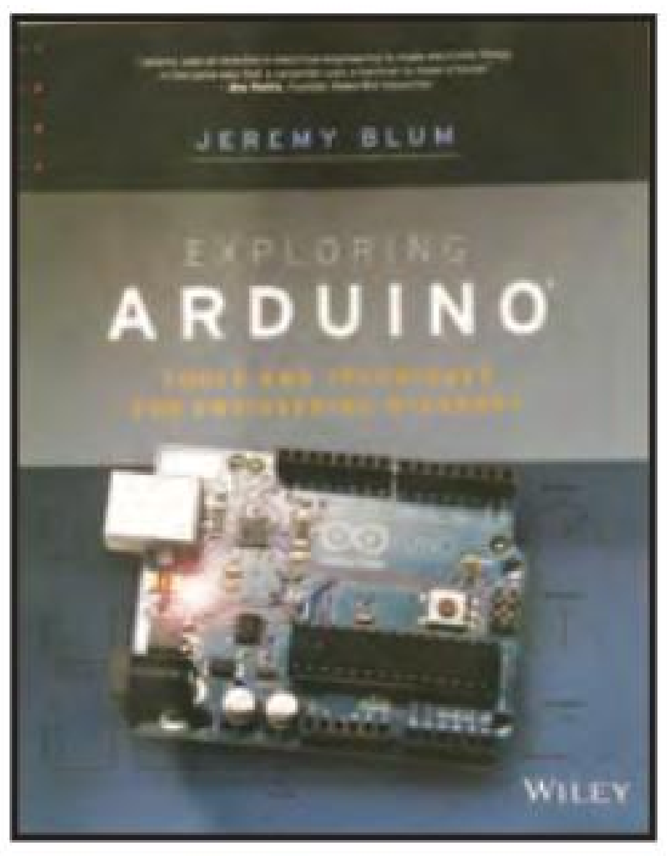

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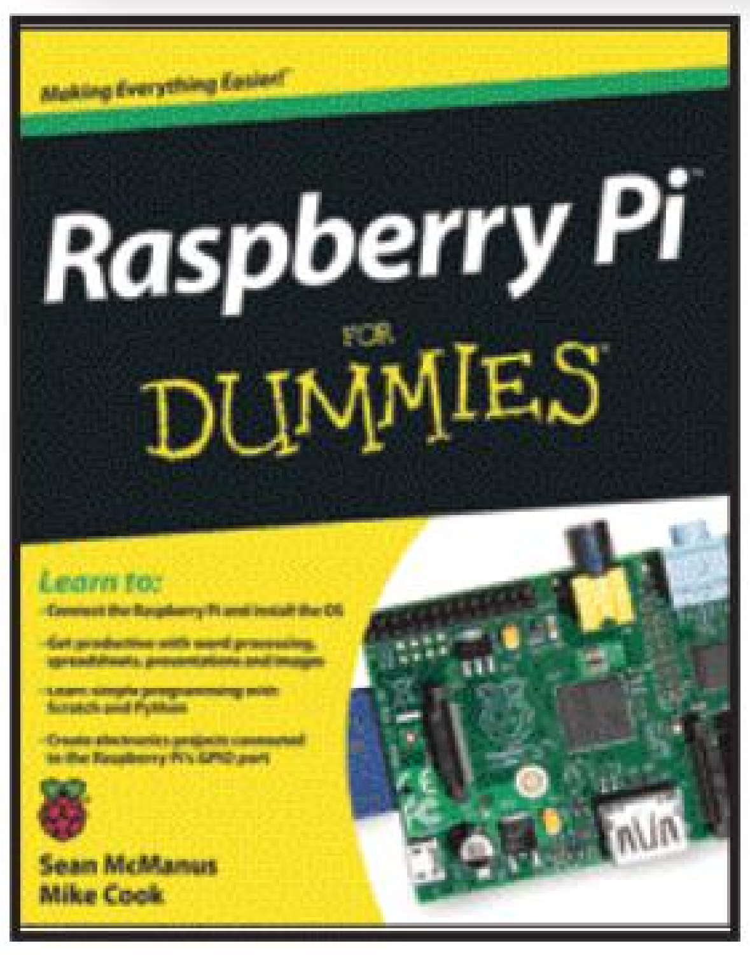

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This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

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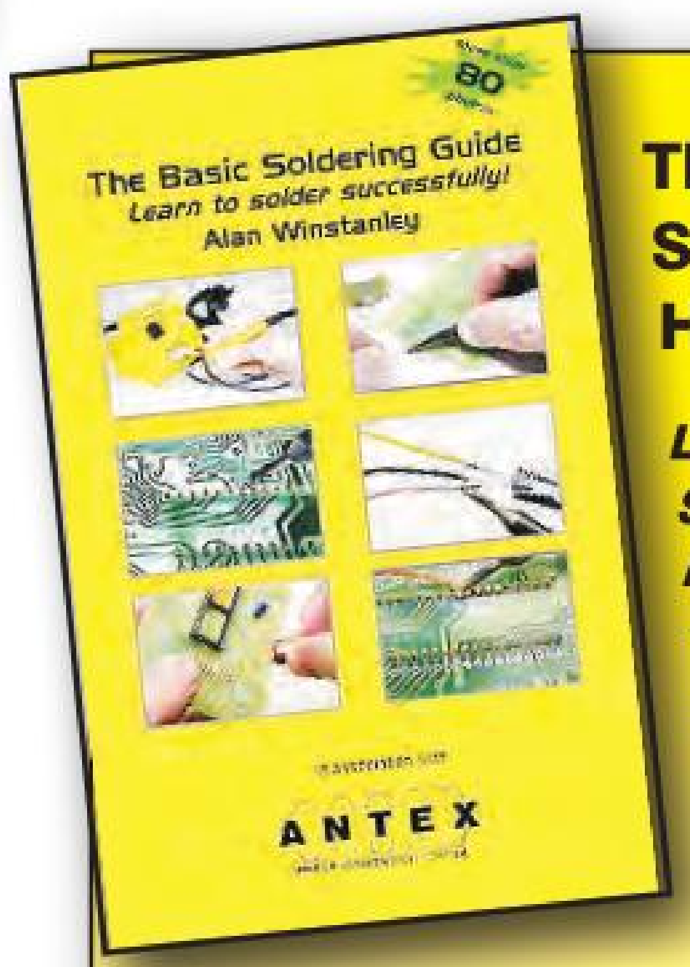

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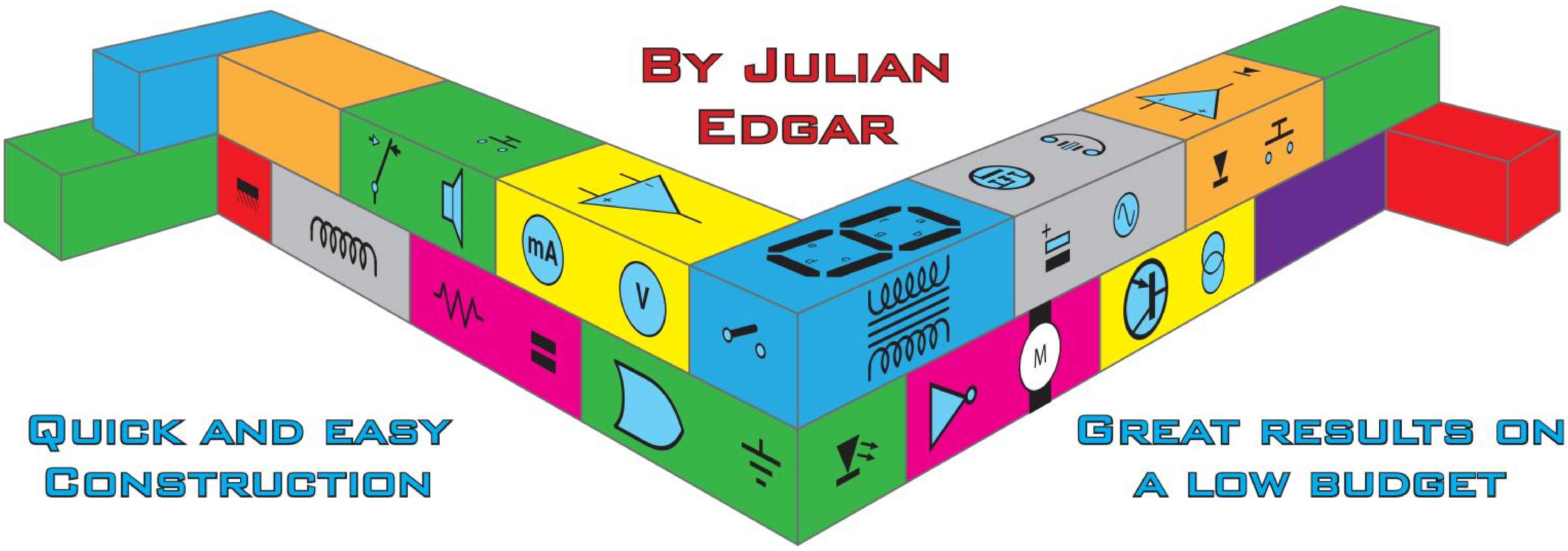


BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

GREAT RESULTS ON A LOW BUDGET

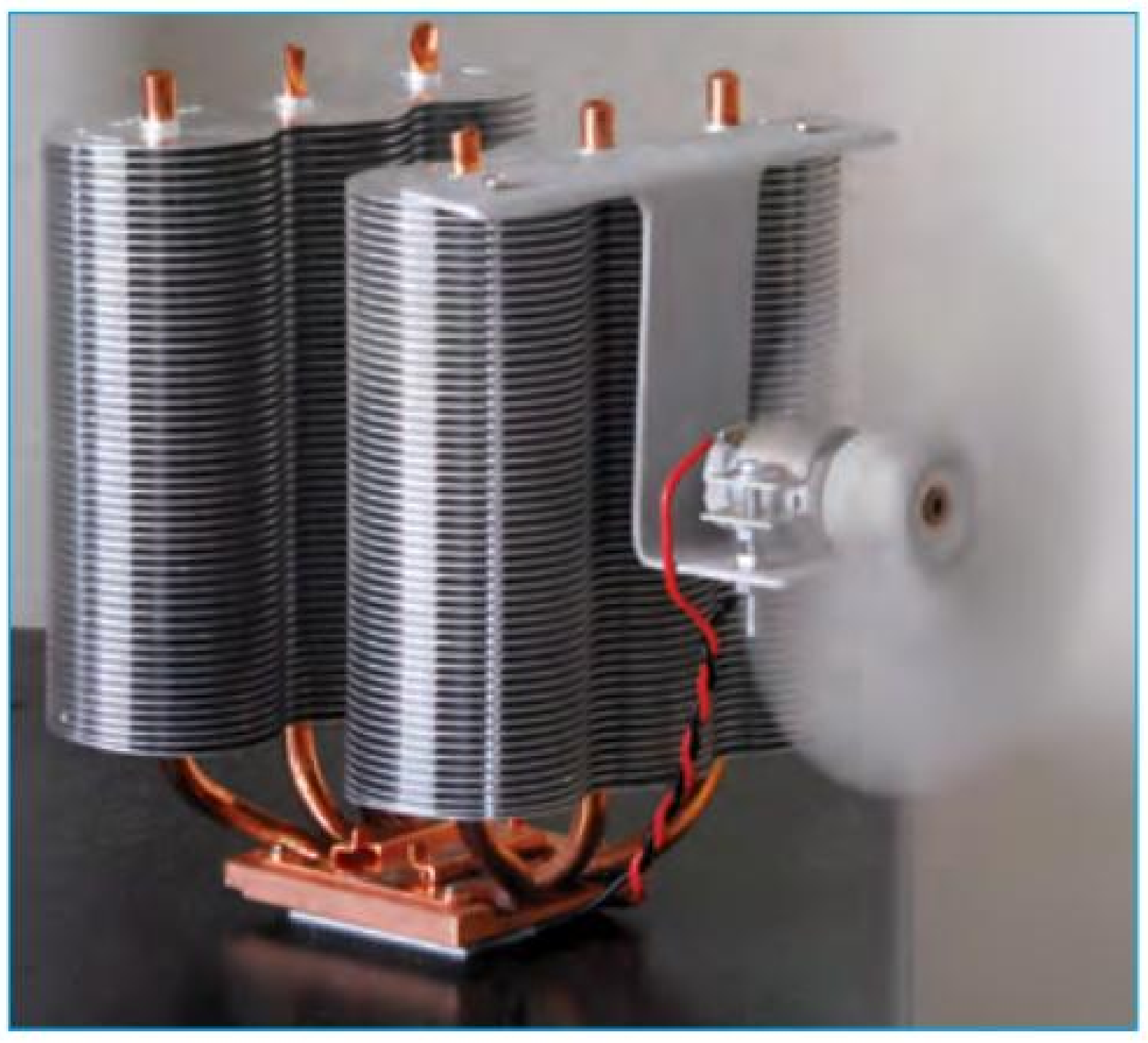
PELTIER-POWERED FAN FOR YOUR WOOD HEATER

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

Here's a great winter project that's fun and educational. If you scrounge some parts and buy a few others on-line, it will also cost you very little. So what is it? This is a small fan that's powered by the heat from a wood-fired heater. (It doesn't have to be a wood heater – any hot surface will do.)

Easy design

The concept is very simple. A Peltier device is sandwiched between the hot surface and a (cooler) heatsink. The Peltier powers a small DC motor that rotates a fan that is positioned to move air through the heatsink. This keeps the heatsink cool, so maintaining the all-important temperature difference across the Peltier device (see box below). Place the device on top of the hot surface and stand back – it's like magic, as the electric fan just keeps spinning, but 'no batteries required'!



Powered by the hot surface on which it is sitting, the fan is a source of amazement to all who view it. Sandwiched between the heatsink and the hot surface is a Peltier deice, that powers the fan. In turn, the fan draws cool air through the heatsink.

If you had to go out and buy every single part, it's probably not worth making – just check eBay for a commercial version of the fan... which was what originally gave me the idea. But in my case, I didn't need to buy anything. I already had a large and visually impressive heatsink that had been salvaged from an old computer. It uses a multi-fin aluminium design with a copper base and copper heat tubes passing through the fins.

Fan, motor and thermoelectric generator

Next up, I needed a fan. The metal fan blade came from my box of old fans, while the motor was one of half a dozen I'd previously bought new. Note that the motor must operate right down to only about 1V, and this motor – though rated at 3-12V – does so. Similar motors are available on eBay for just over £1 – do a search under 'hobby motor'. To match the hole in the fan blade with the smaller shaft diameter of the motor, I made an adaptor by using a short length of the ink tube from inside a ballpoint pen. This was a press fit over the motor shaft, and then by opening-up the hole in the fan blade with a small-diameter drill, the blade became a push-fit over the shaft. You'll probably need to do something similar. Note that while I used a metal blade, if you are careful not to place the assembly where it's really hot, then a plastic blade is fine.

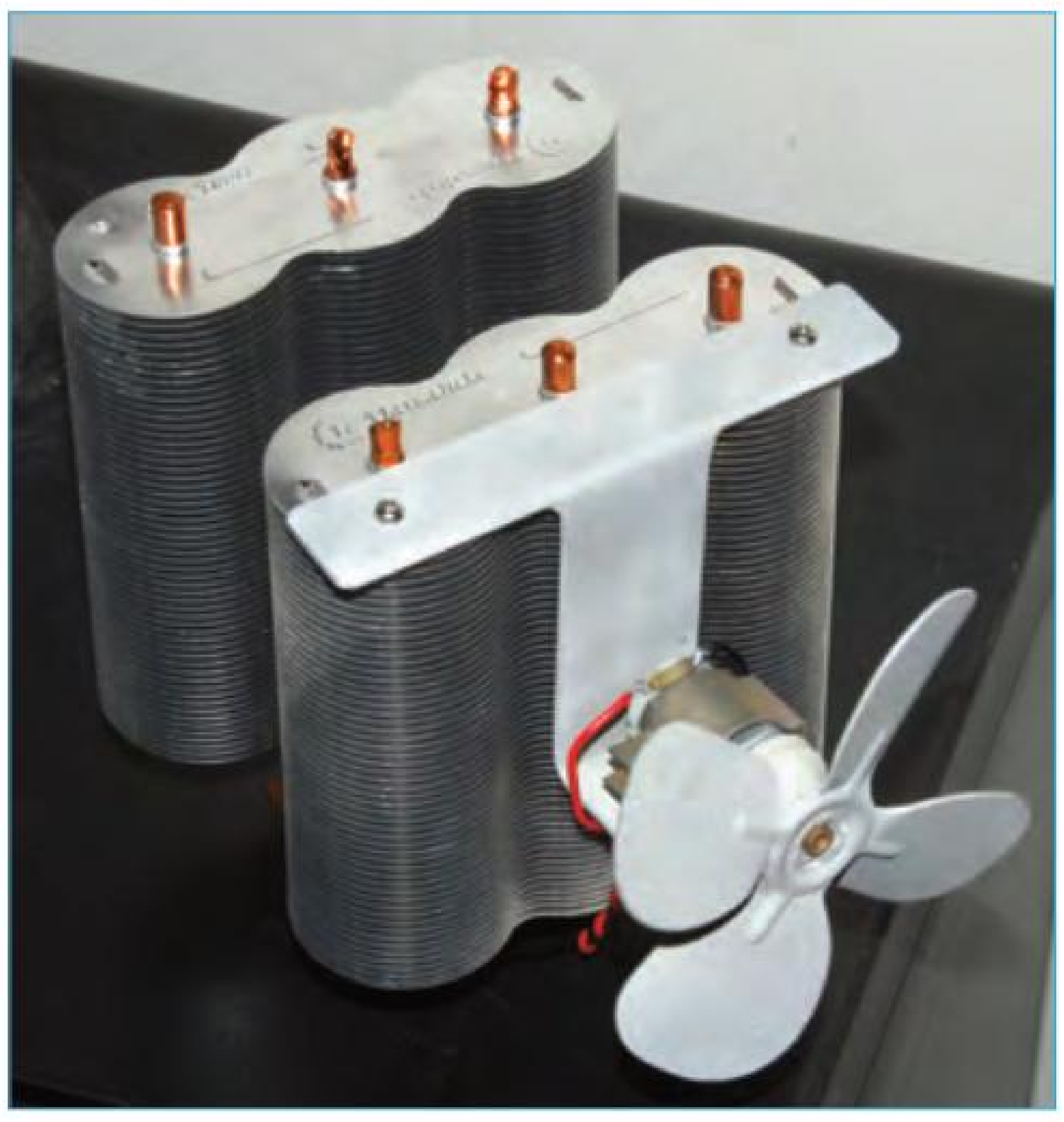
A bracket positioned the fan and motor appropriately, and I chose to place the fan in front of the heatsink but run the fan backwards, so that it was drawing air from the room and then blowing it back through the heatsink.

And the Peltier device? I used a 40 × 40mm TEC1-12708 device from eBay – item 153185320786, under £3 including delivery.

Heat in electricity out

The Peltier effect is the action of heating or cooling at an electrified junction of two different conductors (usually semiconductors), named after French physicist Jean Peltier, who discovered it in 1834. When a current flows through a junction between two conductors, heat may be generated or removed at the junction. In other words, it is a reversible effect;a Peltier device can be used as a thermoelectric generator (heat in, electric current out, as here), or by supplying electric current it can act as a cooler. Such coolers are not particularly efficient or effective, but do have the great advantage of no moving parts or pumped liquid which can leak.

It is important to note that it is not the level of temperature that generates electricity, rather the temperature difference across the two sides of the Peltier device that produces the effect.



The bracket that holds the fan motor in place was made from scrap aluminium. This fan blade is metal, but I also trialled the design with a plastic blade that worked fine. ***However, this is not a device to ever leave unattended!***

Assembly and positioning

You could make a clamp that held the Peltier device to the heatsink, but I took the easy way out and just placed it under the heatsink, the weight of the heatsink and fan pushing down on the Peltier. The assembly was then placed on the flat top of the wood stove. I chose not to use any heatsink compound – no doubt efficiency suffered, but there was also no mess!

With my initial location, the heatsink got hot and over time the temperature difference across the Peltier device lessened and so the fan slowed. However, I then realised that I'd placed the assembly near to some vents in the top of the wood heater, through which hot air was flowing. This heated the heatsink more rapidly than the fan could cool it. Moving the assembly to a location where there were no vents fixed that, with the fan then running continuously. Incidentally, at this location, the heater's metal surface was 120°C while the heatsink immediately on top of the Peltier was about 50°C – a good 70°C difference. After running for several hours, the fan got faster. That's probably because the motor's bearings loosened-up, which in turn caused the fan to speed-up, which in turn caused the heatsink to work better, which in turn boosted the temperature difference across the Peltier, which in turn… positive feedback – I am sure you get the idea!

More experimentation showed that for the hot side, the minimum surface temperature at which the fan would run was about 90°C, so anything between 90° and about 130° should be fine.

Use it carefully

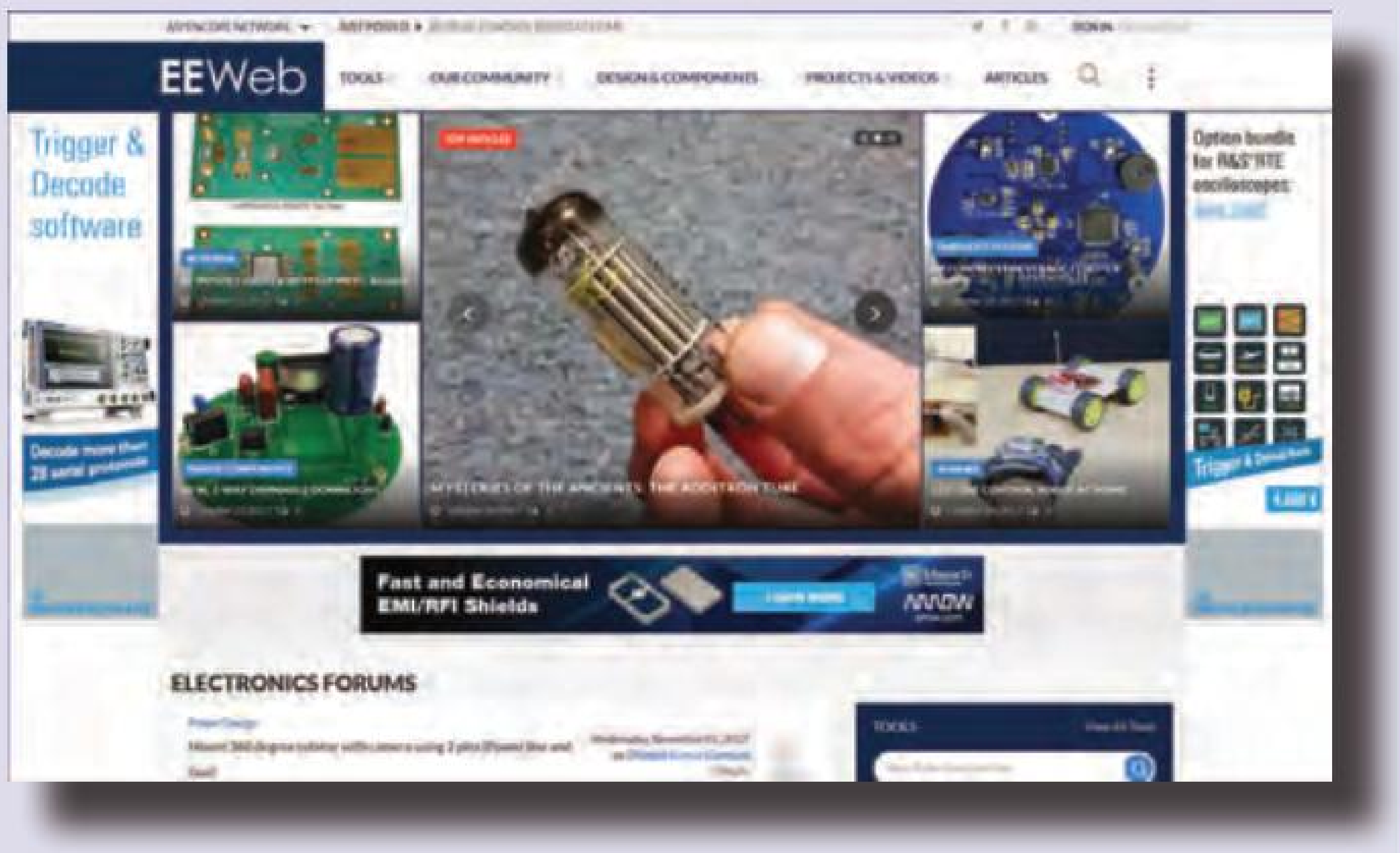
Take care and use this device sensibly. The heater I used is a double-wall design, thus explaining the 90°C to 130°C surface temperature. If the top of your heater is really hot (eg, an old-fashioned cast iron design) you'll probably just melt the Peltier, wiring, motor and fan. **Don't leave the device unattended, and while it's a lot of fun, it's not for use by children.**

The commercial units claim the fan moves air around the room, improving your heating system. Given the power of the system, that seems highly doubtful, but viewed as being just for fun, it's a great conversation piece!

Next month

In January 2019's *Electronic Building Blocks* we'll look at a very handy PWM *Motor Speed Controller* that can handle 6-60V, 30A DC, and is supplied complete with display and control pot.

EPE Chat Zone has a new home...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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
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Next Month

Content may be subject to change

The Altronics Mega Box

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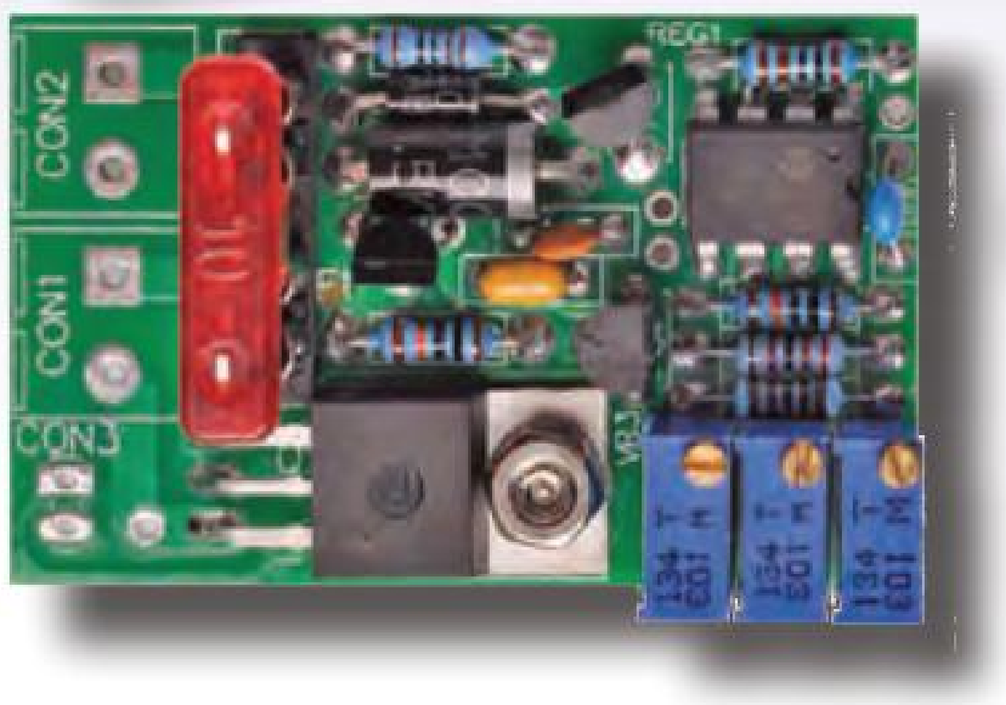

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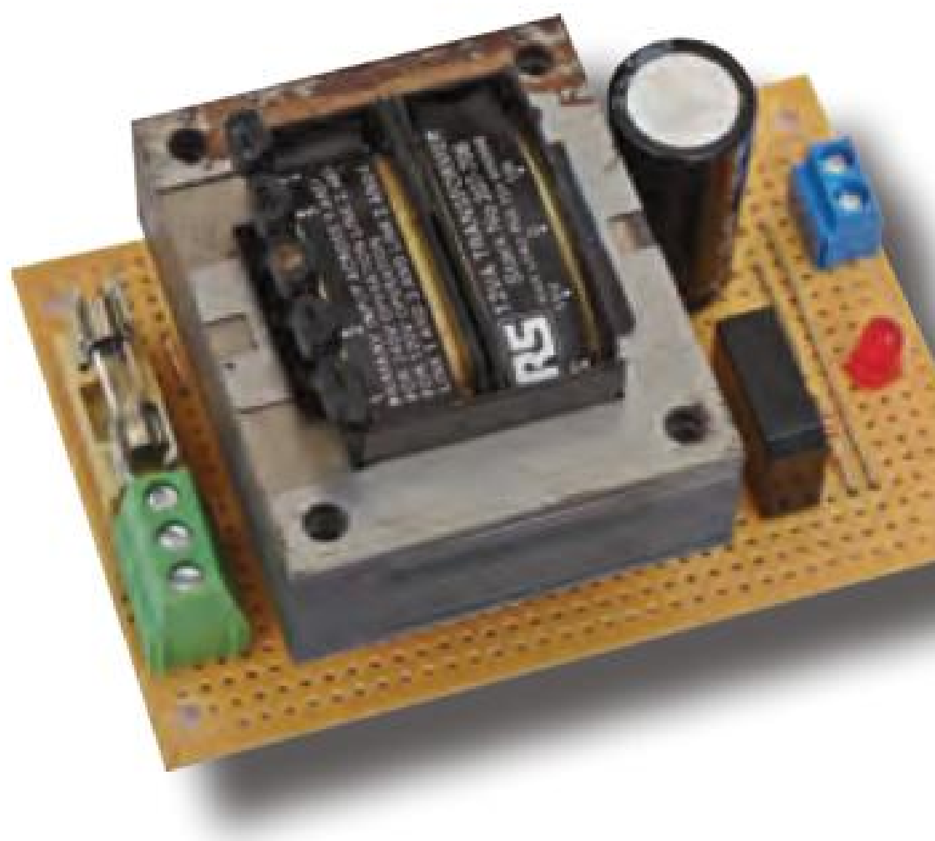
Low-cost Electronic Modules – Part 12

Next month, we'll look at modules based on the nRF24L01+ chip, a complete wireless data transceiver capable of up to 2Mb/s over modest distances, in the 2.4-2.5GHz ISM (industrial/scientific/medical) band. It has a standard SPI interface, making it easy to use with any microcontroller.



Teach-In 2019 – Part 2

In *Part 2* of *Teach-In 2019* next month, we will be looking at AC to DC conversion, explaining the construction of power transformers and wiring configurations for series and parallel operation. We will look at half- and full-wave rectifiers and our *Practical Project* will feature the construction of a simple 18V 0.5A raw DC supply.

PLUS!

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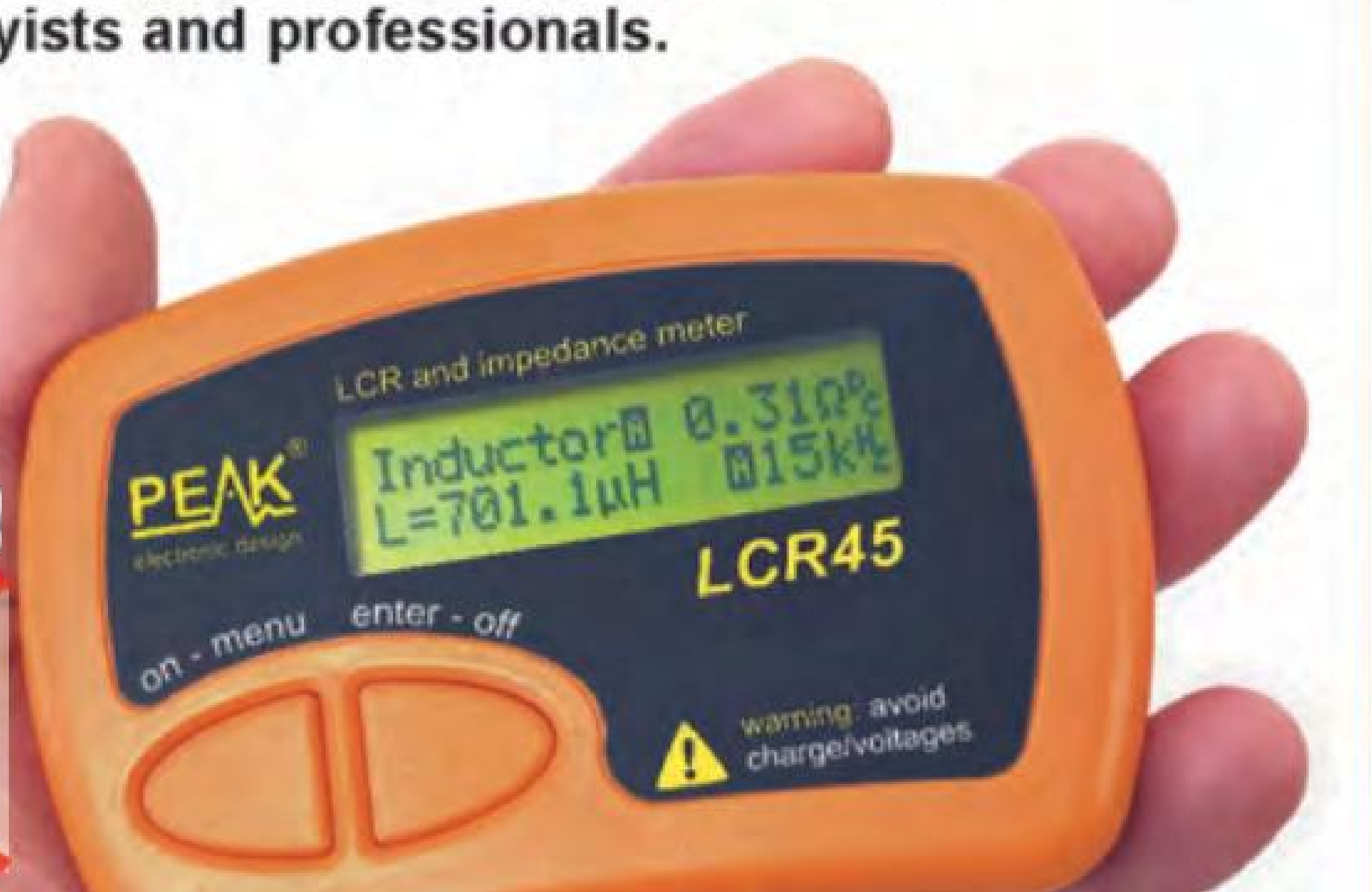
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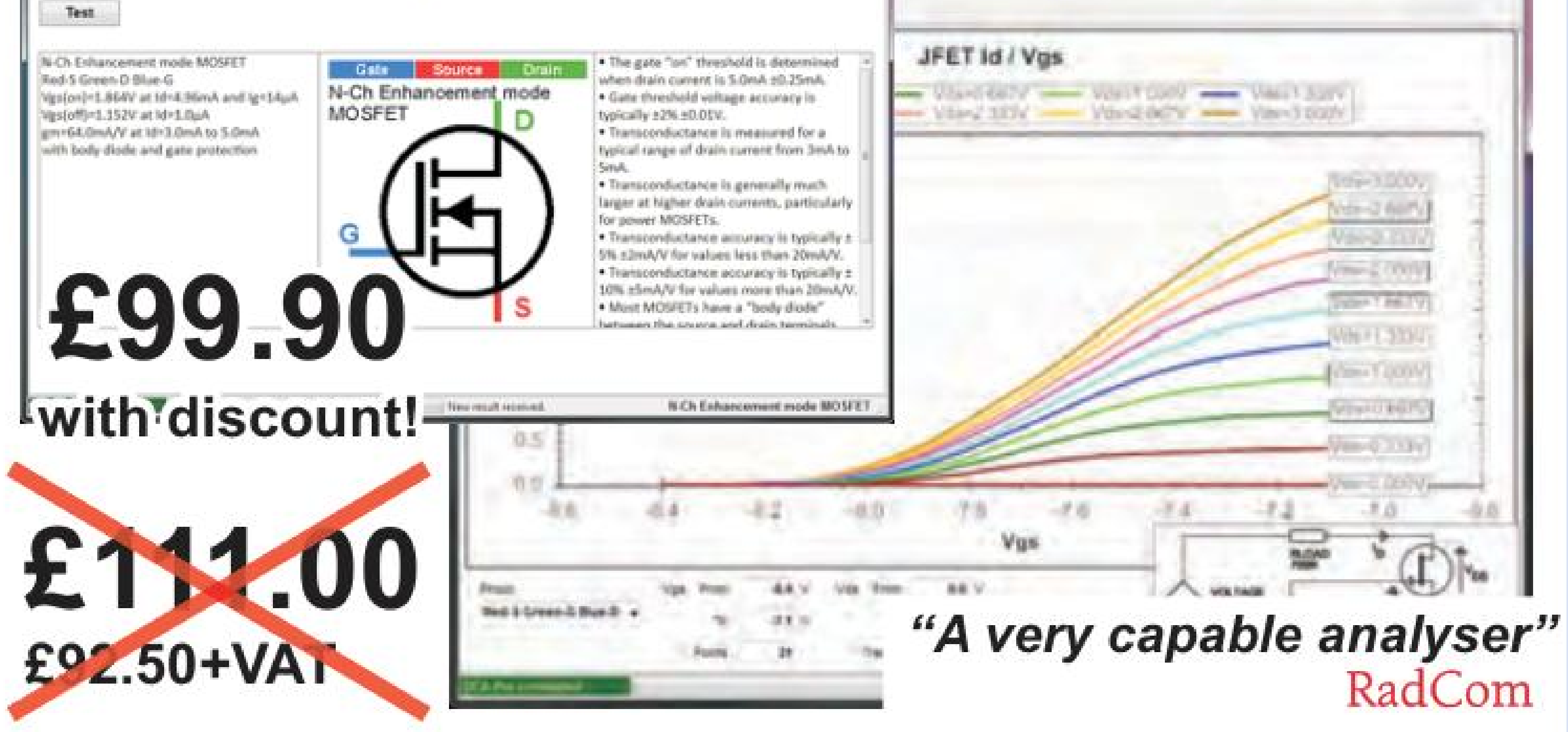
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